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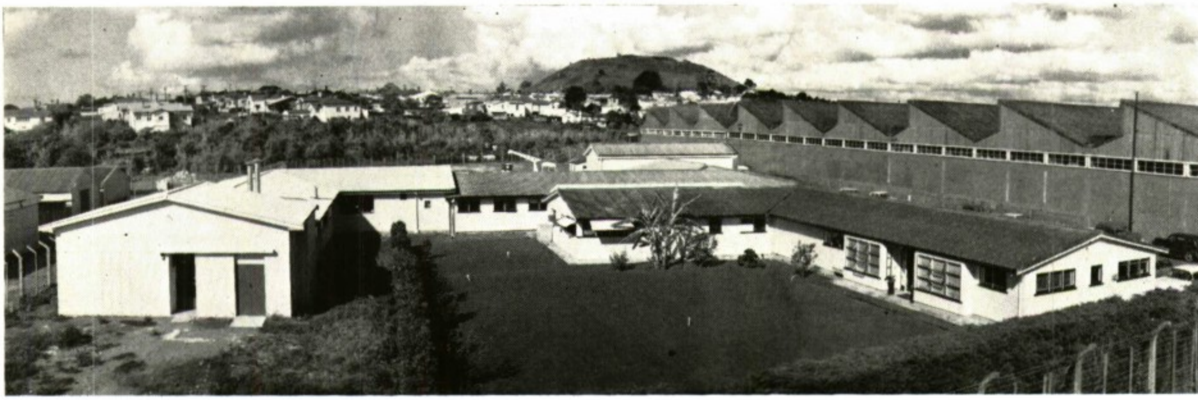
NAVAL RESEARCH LABORATORY, NEW ZEALAND



B. H. Olsson, O.B.E., B.Sc.
Director

Introduction

The Naval Research Laboratory was established in 1955 to take over and expand the small amount of defence research for the Navy that had previously been carried out in New Zealand by various sections of the Department of Scientific and Industrial Research. Initially, most of the effort was concentrated on the local application of new methods of acoustic submarine detection and acoustic mine-hunting techniques but the work was soon widened by the commencement of a more general study of acoustic propagation in the ocean, by the development of new techniques where necessary and practicable and by the introduction of other associated projects and, later, metallurgy.

New Zealand has a population of under three million people with agriculture and other primary produce being the main exports. Only in recent years has secondary industry been introduced on a significant scale and, as yet, the country has little of the large scale industrial capability on which research laboratories elsewhere depend heavily. Therefore, in carrying out a scientific project, particularly where the development of equipment is involved, the New Zealand scientist must usually try to find ways of using the limited resources that are available in his laboratory to achieve the desired result. This forces him to reconsider how similar work has been done overseas and to re-examine the fundamental science on which the project is based in order to find, if possible, a better, simpler and cheaper way of doing the job. The need for this approach in turn affects the design of the laboratory and the facilities and type of scientists and technicians that must be provided.

To provide easy access to heavy engineering as well as other services, the Naval Research Laboratory (see illustration above) is situated within the boundaries of the Naval Dockyard in Auckland. The Laboratory includes offices, workshop areas, store, library and air-conditioned laboratories covering, at present, an area of about 13,000 sq. ft., but it is planned that this area will be increased significantly over the next two or three years.

For work at sea, the Laboratory has the full time use of a converted minesweeper, RNZFA Tui (Fig. 2). The ship, which has a full load displacement of nearly 1,000 tons, is fitted with steam and electric winches for handling deep anchor wires and for cable laying, an air-conditioned laboratory (about 230 sq. ft.) and accommodation for six scientists in addition to the complement of 24 officers and crew. Additional equipment, such as

FIG. 2. Research ship R.N.Z.F.A. "Tui" at Raoul Island.

a deep echo sounder, extra radio communication facilities, gyro-magnetic and gyro compasses and cargo handling derricks, have been fitted to assist in carrying out the scientific programme. The ship can steam at 9 knots and has an endurance of about 16 days at sea on scientific work.

To provide facilities for long term statistical studies of the ocean, a permanent field station was established in 1957 on the east coast of Great Barrier Island. This station (Fig. 3) which looks eastward across the Pacific Ocean, is about 50 miles by sea from the main laboratory. The field station includes a laboratory and living quarters for a permanent caretaker and scientific staff. Hydrophones and other sensors such as temperature and swell transducers which are laid several miles out to sea and connected by cable to the field station are used for gathering acoustic and oceanographic data on a long term basis. In 1962, a data telemetry system was installed between the field station and the main laboratory so that experimental trials and scientific studies can be carried out live at the Naval Research Laboratory. As well as reducing the time that staff had to spend in the field, the provision of the telemetry system has greatly increased the effectiveness of the work based at the field station.

Administration And Programme

The Naval Research Laboratory is part of the Ministry of Defence, for whom it is administered by the Naval Board. The Commodore, Auckland, has responsibility for operational aspects of the programme and the Captain Superintendent of the Dockyard provides services such as accounting, works, staffing and stores procurement.

The Laboratory programme covers the following fields:

- Underwater acoustics including military oceanography;
- Acoustic submarine detection (particularly passive);
- Target classification;
- Mine countermeasures;
- Data processing requirements for these subjects;
- Metallurgy and corrosion research;
- Operational research (to a limited extent only);
- Advice and assistance in these fields to the RNZN and RNZAF.

A Working Group comprising representatives of the Naval Board and Air Board, officers from the Naval and Air operational commands, the Scientific Adviser to the Ministry of Defence and senior scientists from the Laboratory meets for several days annually to consider in some detail the proposed Laboratory programme for the next few years. Their recommendations, after consideration by the Naval and Air Boards and ratification by the Ministry of Defence, become the approved programme for the ensuing year. In this way, the needs of the Services are introduced and priorities assigned so that the Laboratory programme can meet as far as possible the most urgent requirements.

New Zealand is an isolated country. However, care is taken to see that this isolation does not apply to the defence research programme. Through periodic visits and the interchange of technical information under information exchange projects with the United Kingdom, Canada, the United States and Australia it has been possible to ensure that the New Zealand defence science programme is complementary to, rather than a duplication of work being done elsewhere.

The Naval Research Laboratory has a staff comprising about 12 professional officers, 30 technical staff, 15 clerical and general staff and 24

FIG. 3. Field Station, Great Barrier Island.

officers and crew of the research ship. The annual expenditure is a little under $400,000 (After 21st November 1967, NZ$100=£46 13s. 4d.) which includes all salaries, stores procurement and the operation of the research ship. A considerable part of the stores item has been spent on such consumable material as underwater cable and explosives but enough has been available for permanent items of equipment for the Laboratory to be reasonably well equipped for acoustics, electronics, metallurgy and oceanographic work.

FIG. 4. Laying of experimental hydrophone systems in 600 fathoms, 20 miles off shore.

Underwater Acoustics

Early techniques used for studying acoustic propagation were based on local experience in geophysics and on Admiralty advice. Two ships were used (one for firing explosives, the other for receiving the signals) with hydrophone systems suspended on floats attached by cable to the receiving ship. The received signals were recorded on commercial amplitude-modulated magnetic tape recorders for analysis in the Laboratory, where suitable bandpass filters and peak pressure and total energy measuring devices were set up.

Before long, it was realised that the use of two ships on a regular basis was not practical. The research ship TUI was available whenever required, but the services of the second ship (a naval frigate or minesweeper) had to be supplied out of the time allocated to naval exercises. These could not be changed at short notice to suit the Laboratory programme and it was not possible to plan the scientific work long enough in advance to be sure that a second ship would be available. The problem was overcome by several significant steps.

In addition to carrying out acoustic propagation studies at various sites round the New Zealand coast, it was realised that there was a need for one typical site where trials could take place in different ocean and seasonal conditions and where background sea noise and similar topics could be studied continuously. This was provided by the establishment of the field station on Great Barrier Island, the particular site being selected after acoustic studies of several likely places had been made. With this station, propagation and detection studies could be carried out using only one ship and repeated observations under different propagation conditions became practicable.

When work further afield was necessary, the co-operation of the Royal New Zealand Air Force was sought. Maritime aircraft were made available for dropping suitable explosives and, with the receiving equipment in the TUI, long range propagation trials could be carried out anywhere round the New Zealand coast. The use of aircraft also enabled trials to be completed in less time than with two ships, thus reducing weather damage to equipment as well as increasing the total work which could be done in any given period. The availability of aircraft did not prove the same problem as it was with naval ships, first because the time involved was much less and secondly because the work could often be combined with the Air Force training programme.

With time and experience, the receiving equipment used by the Laboratory for acoustic work has been modified and extended in capability. The introduction of transistors, in particular, has led to considerable improvements. Recording is now done on instrumentation-type FM tape recorders. Two systems are now used as standard, the particular one to be used at any time depending on such local conditions as available shelter and weather. One system uses several miles of relatively cheap cable to connect hydrophones laid on the sea bed to the ship (Fig. 4). The second uses a specially developed telemetering buoy with a radio range of about 10 miles. Hydrophones, incorporating low noise transistor pre-amplifiers are used with both systems.

In the Laboratory, also, improved methods of analysis have been introduced. New equipment was designed and built to give semi-automatic determination of energy levels and correlation values in several frequency bands simultaneously and a Pace TR10 analogue computer has been extended and modified to plot sound rays automatically.

The study of underwater acoustics has involved a considerable amount of work on military oceanography. This has involved the recording of sea surface temperature, temperature and salinity structure as a function of depth, velocity meter measurements to 20,000 ft., prevalence of the deep scattering layer and refraction and reflection profiling of the ocean floor.

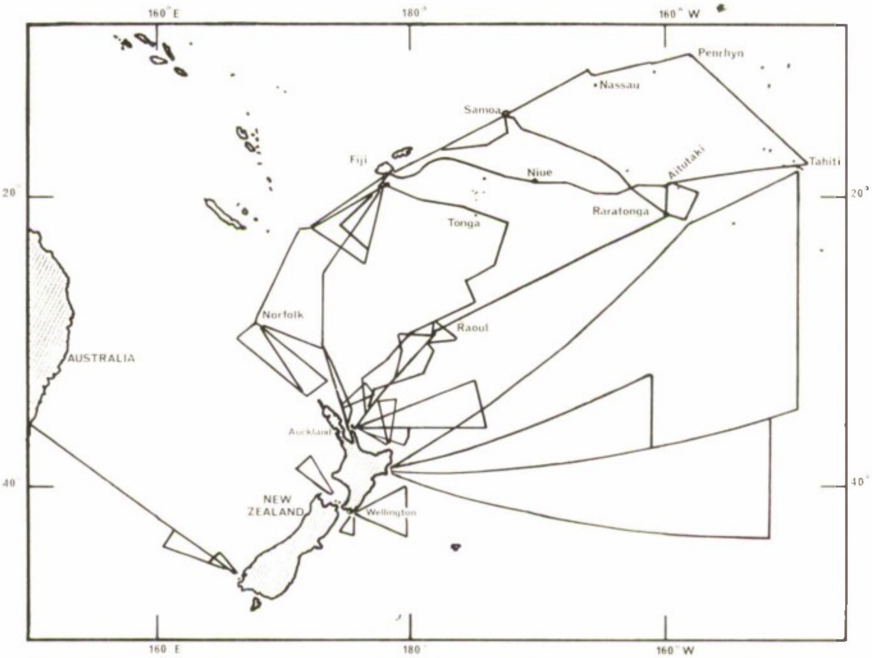


FIG.5. Area covered by aircraft or research ship for acoustic and oceanographic research.

In common with other countries, New Zealand has a shortage of professional scientists and, because of the limitations placed on publishing scientific papers and other security restrictions, this is of particular concern to establishments working on defence science. To assist in meeting this problem and to implement the Navy Board's policy of assisting University and other research organisations with facilities for research at sea, the Laboratory from time to time arranges unclassified oceanographic cruises, inviting outside scientists to share in the work.

Acoustic and oceanographic studies have now been carried out over a wide area of the ocean surrounding New Zealand (Fig. 5) and in many places it has been possible to repeat the observations under both summer and winter conditions. Also, in addition to the areas shown in the figure, a number of very long range acoustic propagation studies covering the Southern Ocean from New Zealand to South Africa and much of the South Pacific Ocean have been made in co-operation with United States establishments.

As well as providing data which have an application for submarine detection purposes, this work has brought to light a number of interesting and new scientific features. Among these has been the discovery and location by acoustic techniques (later confirmed by other means) of several active underwater volcanoes nearly two hundred miles from the coast of New Zealand. The ambient noise level in the South Pacific Ocean has been found to be both lower and different in character from that reported elsewhere, this being partly accounted for by the sparseness of shipping in this area and peculiar local biological activity. This has an obvious implication in relation to submarine detection systems. The very long range acoustic propagation experiments in the Southern Ocean (over a path length of up to 5,500 nautical miles) have enabled the Sofar channel which rises to the surface in high southern latitudes to be studied and has shown that the Southern Ocean appears, from the acoustic evidence, to be more turbulent than the ocean in similar northern latitudes.

Data Processing

Many facets of the research programme of the Naval Research Laboratory have led to data processing requirements, and most of these could not be met economically by use of commercial equipment. A considerable amount of research and development in this field has therefore had to be done.

The underwater acoustics work has required analogue and digital analysis equipment as well as equipment capable of translating raw data into a form suitable for computer analysis. Typical of these has been the development of semi-automatic, multichannel energy and correlation loss measuring equipment for analysis of signals received from explosive sources and an automatic acoustic ray path plotter.

Several special-purpose digital processors have been developed for the submarine detection pro-

gramme. Research has been directed towards the study of parallel computation of data rather than serial in order to handle a large number of data with relatively slow and less expensive computing elements. The advent of integrated circuits, and the faster operating times that they give, makes possible the use of series-parallel computation with time compression. This allows a number of independent sources of data to be handled at high speed in series with input and output transfers taking place in parallel in real time (Fig. 6).

The telemetry of data has been studied by the laboratory for a number of years. Multichannel analogue systems, such as that between the Great Barrier Island field station and the main laboratory, have been used where it has been necessary to retain the amplitude as well as the frequency content of the original signals. These systems are now commonly used in acoustic propagation studies without loss of information. Where amplitude information is of less importance (as for instance in some forms of submarine detection) multiplexed digital telemetry systems have been used. Good results have been achieved over distances of several hundred miles using commercial telephone lines, involving combinations of open wires, underground cables and microwave and open wire carrier systems. The development and use of data telemetry has added significantly to the laboratory capability in a number of fields.

FIG. 6. Development of new type data processing equipment.

Metallurgy

The field of metallurgy was included in the Laboratory programme about three years ago. A new wing was added to the Laboratory for this work and the metallurgical section is now well equipped to provide a day-to-day service to the Naval Dockyard and to carry out the longer term research projects that arise.

Studies on corrosion form an important part of this work. New classes of ships now being introduced into the Navy are designed to tighter specifications than in the past and metallurgical advice is needed to minimize deterioration and to ensure that the right materials and techniques are used when repairs become necessary. The effects of local waters and conditions appear to be different from those reported from the United Kingdom and the United States and a continuous effort is necessary to avoid early deterioration of hull structure by corrosion. Machinery corrosion has also been studied, most of the effort being concentrated initially on boiler tube failures and how they can be reduced.

The laboratory is equipped to carry out physical testing of metals (tensile, impact, hardness and fatigue properties) and also non-destructive testing (radiography and ultrasonic, magnetic and dye-penetrant flaw detection). Raw materials are supplied to New Zealand from many sources and the RNZN is often faced with major ship repairs using unfamiliar metals. Before use, these are tested in accordance with recognised specifications and such characteristics as low temperature embrittlement transition curves established. After acceptance, production controls such as crack detection and radiography of welds are provided by the laboratory.

FIG. 7. Preparation for radiography of tail shaft sleeve cast by Dockyard.

Foundry procedures are also studied. With little suitable industrial background available, the Dockyard often has to solve casting problems that would not arise overseas. Most large castings are "one off" jobs and need research effort to ensure that a homogeneous casting of the right quality is produced (Fig. 7). A research programme on this topic aims to determine the effect that casting variables under local conditions have on the physical properties of a casting.

Other work done by the metallurgical section includes the testing of petroleum products used in naval ships and advice on protective coatings such as paint and epoxy resins.

Assistance to RNZN and RNZAF

The Naval Research Laboratory gives assistance whenever necessary to the Navy and the Air Force in solving specialized problems. Some of this work is of a routine nature such as degaussing and noise measurements of naval ships, advice on radio communication problems and forecasts of acoustic conditions for sonar and airborne detection systems.

Other projects, such as the metallurgical work mentioned earlier, may carry on for a considerable time. The laboratory has also carried out a large number of surveys of the sea bed in connection with mine-countermeasures and this has led to several longer term research projects. Some operational research studies have been carried out and the laboratory is also involved from time to time in the analysis of naval and air maritime exercises. Measurement of the characteristics of sonars installed in naval ships are made periodically in order to ensure that they are operating correctly and, where possible, suggestions are made to improve their efficiency. Associated with this work is a long term study of sonar detections with the aim of assisting target classification and understanding the causes of non-submarine echoes.

Although the laboratory is carrying out much research and development that potentially may add to the capability of the Navy and the Air Force in the future, it is through direct service work that the laboratory is able to assist most at present. This type of work is therefore of considerable importance to the laboratory, although a balance has to be maintained between it and the longer term research and development programme on which it is based and without which it would be ineffective.

Mr. Denis Healey, Minister of Defence, leaving the Admiralty Research Laboratory after his visit on 10th October, 1967.

ANTIFOULING PAINTS AND PROCESSES

C. D. Lawrence, O.B.E., Ph.D., D.I.C., B.Sc., F.R.I.C., R.N.S.S.
Central Dockyard Laboratory

The prevention of fouling of the underwater area of a ship's hull is a matter of great importance to a maritime nation. It is also one of direct concern to a marine engineer, since fouling increases the frictional resistance of the hull to the water and results in a decrease in the operational efficiency of the ship and a rise in the oil fuel consumption required to maintain the ship's speed. In addition, there is the increase in wear on machinery that this entails and the extra expense of docking the vessel for cleaning the underwater area.

Other adverse factors caused by fouling are the blockage of the salt water pipe systems of ships and the obstruction of tubes and conduits of power stations and oil refineries situated on the coast which use very large amounts of sea water for cooling and other purposes.

Effect of Fouling on Ships' Speeds

The prevention of hull fouling is particularly important to Naval ships since they may be anchored for considerable periods in highly fouling waters and they must always be capable of operating at maximum efficiency and at high speeds at short notice. Fouling occurs almost entirely when the ship is stationary and commercial ships are normally at rest in ports for only very limited periods. An exception to this general rule occurred last year when, owing to the seamen's strike, United Kingdom ships were laid up in ports for periods of up to six weeks. The R.M.S. *Queen Mary* was particularly affected by fouling which grew in Southampton Water and she gave a very poor performance indeed on her subsequent Atlantic crossing which occurred at reduced speed and was accompanied by vibration trouble. As a result it was found necessary to give her an emergency docking to remove the fouling and re-paint her underwater area. The contrast in her performance on her next crossing was very striking and, although this ship is some 30 years old, she equalled her original speed which won her the Blue Riband.

There have been a number of trials on Naval ships in which the propulsive force was estimated by the shaft horsepower determined over measured course at periodic intervals out of dock. When a ship is not adequately protected by antifouling paint, the rise after six months can be as high as 100% at 15 knots (Fig. 1). The percentage increase in shaft horsepower was less at 25 knots because of the relatively greater effect of wave making as opposed to frictional resistance at this higher speed[1]. The behaviour of painted steel test panels towed in model basins has also confirmed these results.

Trials by the British Ship Research Association on the vessel *Lucy Ashton* indicated that an increase in resistance by over 30% was observed

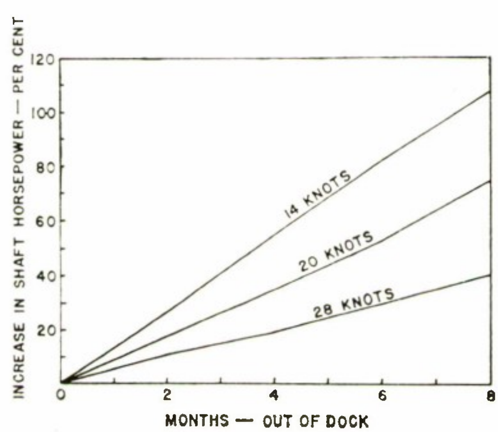


FIG. 1. Percentage increase in shaft horsepower required to propel a U.S. Navy destroyer at different speeds after various periods out of dock.

FIG. 2. Photograph of the outer bottom of a naval vessel showing calcareous tube worm and tunicate fouling which has settled after exhaustion of the antifouling point.

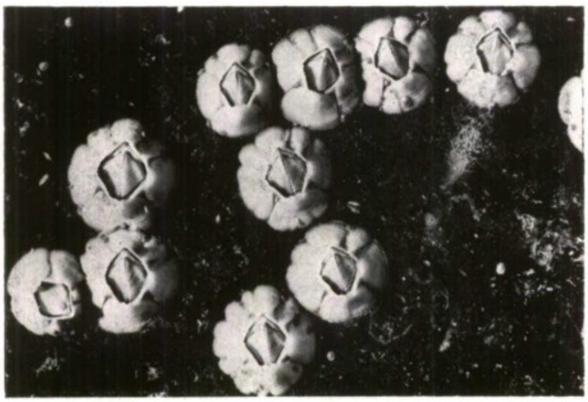


FIG. 3. Photograph of barnacles (Balanus balanoides) growing on a non-toxic painted surface (magnification x 0·67).

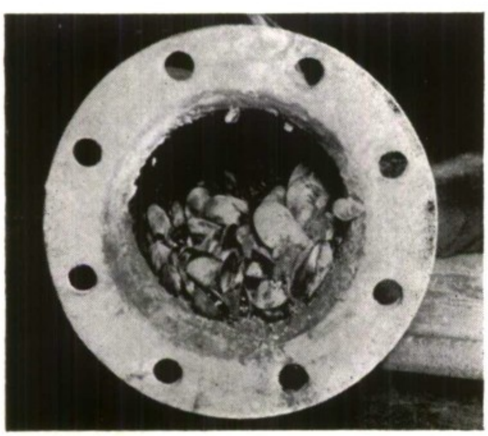


FIG. 4. Showing the blockage caused by mussel fouling in a 5 in. sea-water fire main in a cruiser.

after the hull had accumulated a fairly light settlement of barnacles[2]. Similar results were obtained with a cross-channel ship, the *Koningin Elizabeth*, after 12 months' service[3].

These results all confirm the extra propulsive force required, and the resulting increase in oil fuel consumption caused by only a relatively small amount of marine fouling on the ship's hull.

Types of Fouling Organisms

In all, there are several thousands of different species of marine fouling, and their nature and propagation depend upon various environmental factors such as salinity, degree of pollution of the water, and especially upon the temperature of the water. Reproduction is very slow in sea water below about 50°F so that in the United Kingdom waters fouling is limited to the season from March to October whereas in the tropics and sub-tropics it can occur all the year round.

Ship fouling is mainly due to a relatively few types of universally-growing organisms which settle on the ship when it is stationary or nearly so. Once these organisms have settled, however, they can remain and grow on the ship, even when it is moving at high speeds. It should be noted that ports vary considerably in their fouling propensity and those situated in fresh water estuaries cause little trouble in this respect. Indeed a stay in waters of low salinity can cause the death and detachment of fouling already established.

The surface becomes coated with a film of slime which is composed of microscopic organisms consisting of bacteria, diatoms (uni-cellular plants) and protozoa. This type of fouling is not of serious consequence but may form the basis of the later settlement and development of macroscopic organisms. This slime formation may be followed by the growth of algae, the most common varieties of which are the brown Ectocarpus and the green Enteromorpha species.

Finally, and sometimes concurrently with the algal settlement, comes the attachment of animal fouling, particularly barnacles, hydroids, and tubeworms (Fig. 2). Wooden boats and structures can also be attacked by gribble and teredos which burrow into the wood.

Of all these fouling organisms, barnacles, species of which occur almost universally, are the ship's main enemy and any successful anti-fouling paint or device must be fully capable of preventing their attachment and growth (Fig. 3).

An example of an organism which is not normally found on ships' hulls but which is, nevertheless, the cause of blockage of ships' fire mains and the intakes of industrial cooling systems is the common mussel (Fig. 4).

Antifouling Processes

Although the use of antifouling paints remains the most effective and widely used method of combatting ship fouling, several alternative methods have been proposed from time to time. Some of these show considerable ingenuity in their approach to the problem and a few have received some prominence in recent years. Brief details are given below of two such systems, one based on high frequency vibration and the other based on a toxic dispersion system.

(a) *Ultrasonic Antifouling System*

The equipment used in the Marconi-Postans so-called Protector system, designed by the Marconi International Marine Communications Company, consists essentially of a transmitter supplying ultrasonic impulses to a number of transducers welded to the hull. Many ship and raft trials were made by Marconi during 1956-60; assessment of the value of the technique was hampered by the continued use on many ships of antifouling paints, and on some of the ships without antifouling paint the system did not prevent fouling.

The Admiralty undertook collaborative raft trials at Portsmouth during 1957-59, using plates vibrated at frequencies of 17 to 25 kc/s and powers represented by 30 to 85 dB. Only at the highest power was any discouragement of barnacle settlement observed and even in this case many larvae did settle and grow normally.

It was concluded that so far as the Royal Navy was concerned, the ultrasonic system could not, at this stage at least, compete with the efficient antifouling paints in present use.

(b) "*Toxion*" *Antifouling Process*

This is a process developed by F. A. Hughes and Co. Ltd., by which a kerosene solution of a toxic material stored in steel tanks on the ship is discharged by compressed air through small pipes fitted in selected positions on the outside of the ship's hull. The small bore dispersal tubes are of pvc and the compressed air is cooled and then supplied by a self-contained unit. The rate of discharge of the toxic solutions is controlled by metering pumps, the plungers of which are adjusted by micrometer screw heads. The discharge is confined to periods when the ship is in port or at anchor.

This particular system is used in conjunction with cathodic protection since it is claimed that the toxic ions are attracted to a negatively-charged hull. The toxic compounds normally used in this process are the alkyl tin compounds, in particular tri-butyl tin oxide (tbto).

This process has certain disadvantages in connection with Naval use but is still under trial in commercial ships, on some of which, however, it has given inconclusive results.

(c) *Other Processes*

Apart from ships' hulls, fouling can occur in pipes supplying sea water on shipboard and an example has been shown in Fig. 4. This type of fouling can be prevented, or at least minimised, by the addition of controlled amounts of sodium hypochlorite solution. Care must be taken, however, to keep these additives to a minimum or otherwise corrosion troubles will result. A convenient method for use on shipboard is to employ a small electrolytic apparatus which generates hypochlorite *in*

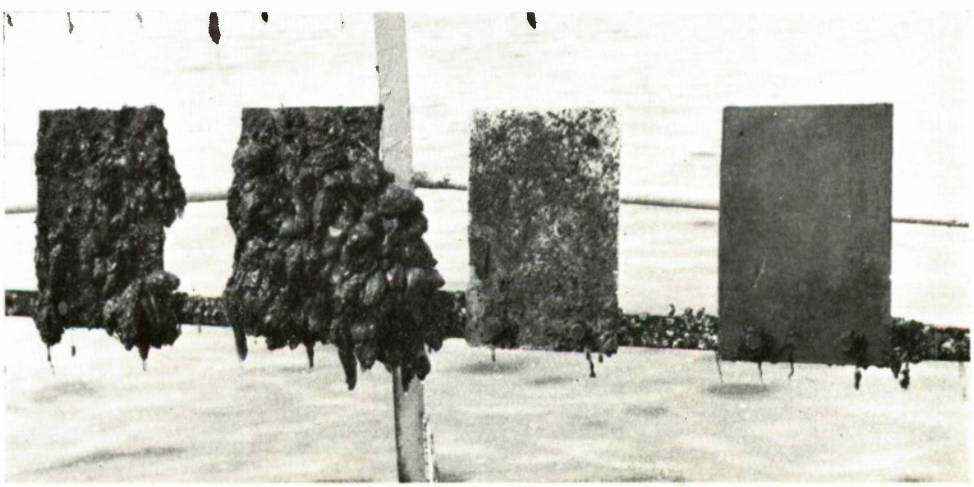


FIG. 5. Comparison of four different metal panels after one-year's exposure in sea water.
Left to right: mild steel, aluminium, zinc and copper.

situ. The increasing use of copper alloy pipes in Naval ships keeps this form of fouling to a minimum.

In the case of installations ashore the pipes or conduits used for cooling apparatus can be fouled by an accumulation of mussels. This can be prevented by the addition of sodium hypochlorite or by chlorination of the cooling sea water. Here again care must be taken to keep the dosage to a minimum.

Antifouling Paints

Historical. The development of anti-fouling surfaces began with the introduction of copper sheathing for use on the bottoms of wooden ships. This gave effective protection both against fouling and against attack by teredos and gribble worms (Fig. 5). However, with the introduction of iron hulls in the last century copper sheathing was used on these with disappointing results due to intensive anodic corrosion of the iron hulls. With the abandonment of copper sheathing came the search for substitutes which would prevent fouling without accelerating corrosion. Some thousands of patents were taken out on a great variety of substances such as mixtures of "clay, fat, saw-dust, hair, glue, oil and logwood." Needless to say most of these compositions were useless and it was not until later in the nineteenth century that antifouling paints of real value were devised. Two of the early paints are worthy of mention, one produced by McInnes, of Liverpool, and the other by an Italian firm in Trieste and known as Italian *Moravian*. They were based on copper and other metallic soaps and were applied as a hot plastic paint over a rosin-based varnish.

Present Toxic Components. It should be observed that the prevention of fouling by means of a toxic paint involves maintaining a lethal concentration of poison in the sea water in immediate contact with the paint surface.

The most widely-used poison for present-day antifouling paints is cuprous oxide which is an excellent paint pigment with a fine particle size. The material prepared by electrolytic processes has a particularly small particle size and is superior in antifouling properties to that prepared by the pyrometallurgical process. A stabilizing agent must be added to prevent atmospheric oxidation.

It is of interest to note that the higher oxide, cupric oxide, is useless as an antifouling agent, although finely powdered metallic copper itself has good antifouling properties. The only other copper pigments in use, and these only for specially coloured paints, are the thiocyanate and the aceto-arsenite.

The most effective of the mercury compounds for antifouling purposes are mercuric oxide and mercurous chloride. Mercuric chloride although extremely lethal to marine organisms is far too soluble to be utilized and is in any event too toxic to humans.

Other inorganic compounds are of little use. Arsenious oxide which was once in favour has now been established as being of little value. Zinc oxide is considered to have a slight reinforcing action when used with copper compounds but is only of limited value.

Certain organic compounds have been shown to have antifouling properties. At present a great deal of attention is being directed to organo-tin compounds and in particular to tri-butyl tin oxide for which good antifouling properties are claimed. More ship trials are needed before a firm assessment of this material can be given but Naval raft trials have so far indicated the superiority of copper poisons. Other organic toxins which show promise are organo-mercurials and certain insecticides such as D.D.T.

Types of Antifouling Paint. In the United Kingdom, commercial ships and liners are painted with proprietary antifouling paints of which there is a considerable selection. They vary in potency and in price from the milder "Atlantic" quality to the more lethal "Super-Tropical" types. The formulations of these paints are in general not disclosed by the manufacturer but they frequently rely for their antifouling property on the incorporation of one or more of the toxic agents mentioned above.

In the case of Naval ships, as indicated previously, their anchorage for prolonged periods in ports and seaways renders them particularly liable to attack by fouling organisms. The operational period of H.M. ships at sea between dry docking is steadily increasing and it is now necessary to prevent, or at least minimize, fouling for a period of up to two years.

The requirements of a good antifouling paint are onerous. It has to be compatible with the anti-corrosive undercoat used. It must be capable of brushing or spray application and it must be able to resist erosive action under conditions of high speed and rough weather. At the same time it must be so formulated that it releases toxins at a controlled rate so that it has a long active antifouling life.

Broadly, antifouling compositions can be classified into two major types, namely, the soluble matrix type and the insoluble matrix or contact leaching type. The soluble matrix type contains an appreciable percentage of rosin which is slowly dissolved by the slightly alkaline sea water, resulting in the toxins being released at a controlled rate. In addition to rosin the medium contains other toughening resins such as oil-modified phenol

formaldehyde and plasticisers such as tricresyl phosphate. An antifouling composition of this type [4] which is now in use on some ships of the Royal Navy has the following composition:

Cuprous oxide	57·4
Asbestine	2·4
Chlorinated Diphenyl	5·4
Oil-modified phenol formaldehyde resin	5·4
Rosin WW grade	16·2
Solvent naphtha	13·2
	100·0

The contact leaching type consists essentially of a strong insoluble matrix such as a vinyl copolymer heavily loaded with a toxic pigment, generally cuprous oxide, to such an extent that each particle is in contact with other particles so that when one is dissolved another is exposed. For various reasons, however, true contact leaching paints are rarely used in practice, requiring modification by the inclusion of a considerable proportion of rosin.

These vinyl types of antifouling paint require to be applied under good climatic conditions or they tend to strip during service use. They are used to a considerable extent by the United States Navy and a typical formulation [5] is as follows:

Cuprous oxide	55·1
Vinyl chloride-acetate copolymer	5·5
Rosin	5·5
Tricresyl phosphate	2·1
Methyl isobutyl ketone	19·0
Xylene	12·8
	100·0

It must be emphasized that antifouling paints are not suitable for application directly to the steel surface of a ship's hull since their metallic ingredients are liable to give rise to corrosion troubles. The outerbottom of the ship should first be cleaned by gritblasting or other similar system and then coated with a wash primer and with several layers of protective paint which can be, for example, either an oleoresinous or a bitumen type. If cathodic protection is used on the ship a coal tar epoxy paint can be used with advantage.

The antifouling paint is then applied by brush or by an airless spray technique. After subsequent dry docking it is usually sufficient to remove loose paint, debris *etc.*, by scraping and damaged areas can be touched-up and the whole area recoated with fresh antifouling paint.

Assessment of Antifouling Paints. Before applying a new or improved antifouling paint on a ship it is necessary to test its antifouling efficiency and this is best done on panels immersed from rafts in the sea and by subjecting it in the laboratory to leaching rate tests.

The site for exposure for rafts should be selected with care and it should be in a clean sheltered area free from fast currents but with sea water of full salinity and frequented by a good range of fouling organisms (Fig. 6). Steel plates normally 15×10 in. and $\frac{1}{8}$ in. thick are coated with anticorrosive paint, and then with the antifouling paint, and immersed in sea water at depths of $1\frac{1}{2}$ and $4\frac{1}{2}$ ft. They are inspected at monthly intervals for the presence of any fouling organisms. A good paint for Naval purposes should remain unfouled for at least three years (Fig. 7).

The compatibility of the antifouling paint with the anticorrosive undercoat is also studied. Provision is also made on the rafts for the application of cathodic protection to the panels by means of

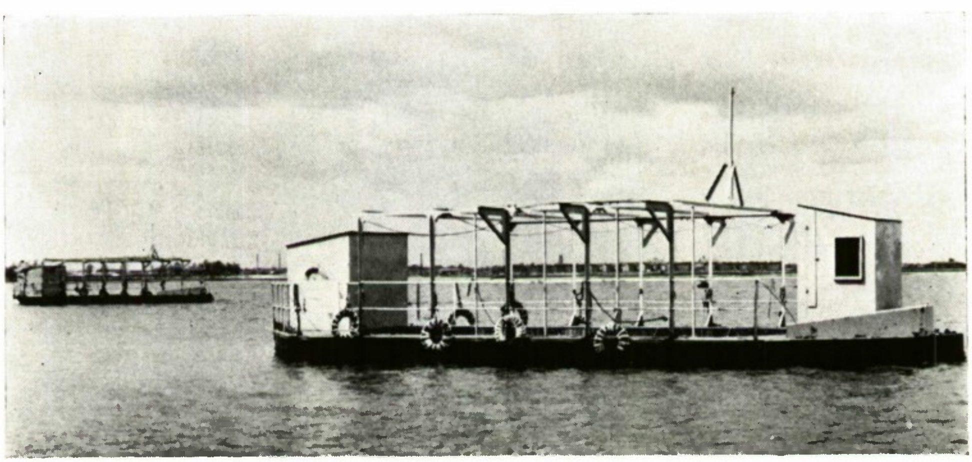


FIG. 6. Two of the four Navy exposure rafts moored in Langstone Harbour, Portsmouth.

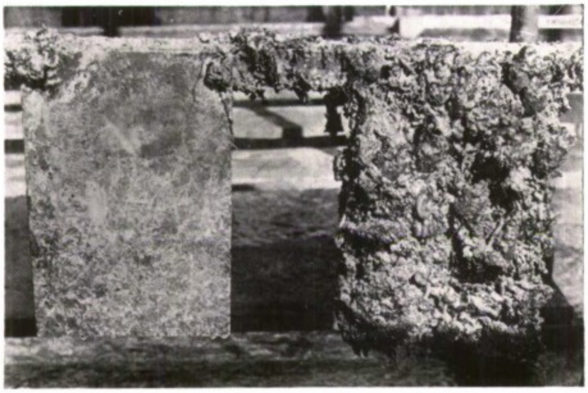


FIG. 7. Comparison of an effective antifouling paint and a non-toxic surface after one year's exposure on the Admiralty rafts at Portsmouth.
This protection against fouling continued for a further three years.

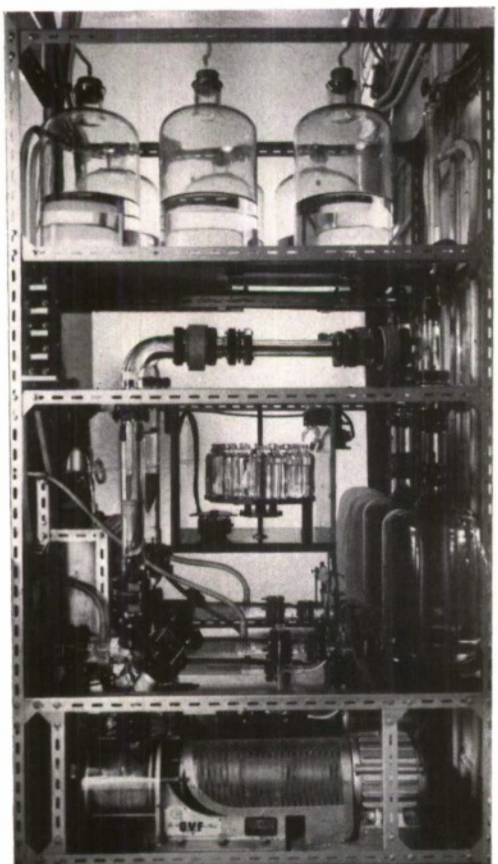


FIG. 8. Apparatus for the mechanical accelerating of leaching rate.

sacrificial anodes of aluminium, magnesium or zinc. Cathodic protection *per se* has no effect on the antifouling action of the paint but it is important that the underlying anticorrosive paint should be resistant to the application of cathodic protection. The protective paint should be capable of withstanding any alkaline attack produced at the steel substrate by slight over-voltage in the system. Coal tar epoxy and vinyl paints are suitable for use under these conditions.

Leaching Rate. This is the rate at which the toxic material is released into sea water. For an antifouling paint to be successful it has to maintain a leaching rate above a certain critical value over the whole of its service life. This critical value is generally taken to be 10 $\mu g/cm^2/d$ for copper and 3 $\mu g/cm^2/d$ for mercury.

Various attempts have been and are being made to accelerate this leaching rate test in the laboratory so that the antifouling efficiency of a paint can be more rapidly assessed. There are two main methods of effecting this acceleration, for example, either by chemical or by mechanical means.

The most favoured method of chemical acceleration in the case of copper compounds is by the use of glycine, although citric acid can also be used. The chemical leaching process can be further accelerated by rotating the painted panels.

Although this chemical method is very rapid its results are open to criticism on the grounds that extraneous factors are introduced. The best method of accelerated leaching is by mechanical means, since this reproduces to some extent the conditions to which the paint is subjected while on the ship steaming at sea. There are two main methods of effecting this acceleration: (a) By rotating a cylindrical surface coated with antifouling paint at high speed in sea water[6]; (b) by passing sea water at high speeds over a static painted surface.

Both methods are being used and the apparatus used in method (b) at the Central Dockyard Laboratory, H.M. Dockyard, Portsmouth [7] is shown in Fig. 8.

Future Trends

The best types of antifouling paint are capable of protecting hulls against fouling for periods of up to two years or even longer. They have, however, certain disadvantages, for example, most of them are relatively expensive owing to the high cost of copper and especially mercury compounds.

Several of the recently-developed organometallic compounds offer promise and it is possible that further research in this field will produce still more effective and possibly cheaper antifouling paints. It is also visualized that a combined attack on the biological and chemical aspects of the problem will lead to the development of anti-hormones,

repellents or metabolic blocking agents which could be used either alone or in conjunction with toxins to give a big increase in efficiency.

One disadvantage of an antifouling paint is that the leaching of its toxic ingredients continues at an increased rate when the ship is in motion and hence when such action is not needed. There is, therefore, a requirement for an antifouling system that operates solely when the ship is at anchor and although, as indicated above, several such systems have been, and are being tried, there still remains a need for further research in this field of endeavour.

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ADVANCED NAVIGATIONAL TECHNIQUES— AGARD Symposium, Milan, September, 1967

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The 14th Symposium of the Avionics Panel of The Advisory Group for Aerospace Research and Development (AGARD) of NATO, was held at the Museo Nazionale della Scienza e della Tecnica "Leonardo da Vinci" in Milan between the 12th and 15th September, 1967, and was attended by about 100 delegates.

The symposium was unclassified, and the 26 Papers laid more emphasis on commercial problems than on the military applications of "Advanced Navigational Techniques." Most authors dealt with aeronautical navigational problems rather than with those strictly applicable to marine users.

The conference was divided into four major sessions, the first of which, entitled "Navigation System Aids and Needs," was intended to outline the requirements of the navigator and to review how successfully these changing needs might be met in the future.

The second session was entitled "Ground-based Navigational Aids for Space and Earth Craft" and this was followed by a series of Papers dealing with "Satellites for Air and Marine Navigation and Traffic Control." The final session dealt with the problems of "Navigation Supporting Technology."

During the course of the first session, it appeared that merchant ships were generally satisfied with the navigational aids already available to them, although the possibility of a world-wide system such as OMEGA would continue to be attractive, particularly if the receiving equipment could be produced inexpensively.

The navigational problems peculiar to special vessels concerned with Hydrographic and Oceanographic research were still largely unsolved. An absolute accuracy of 0·1 nautical mile was needed for deep oceanographic survey, while the inshore accuracy requirement was of the order of 25 ft.

However the greatest and most urgent problems were apparent in the aeronautical environment, where it was becoming increasingly important to utilize air space more efficiently.

Concern was centred on the North Atlantic air lanes, where at the moment about 800 aircraft are operated daily. The traffic density peaks twice during this period when as many as 100 aircraft are airborne at the same time. It is estimated that this figure will treble by about 1980, but the guidance and control problems, already serious, will be acute by the early 1970s. An increasing use of automation will be required in order to improve the reliability and speed of communications with, and surveillance and navigation of, air traffic.

The second session opened with a Paper which reviewed the current state of the OMEGA system. Four stations are already working in a limited operational mode and approximately 50% of the Northern hemisphere is covered by them.

Financial approval has not yet been given to implement a world-wide system of eight stations.

Other Papers suggested improvements in the OMEGA signal format, and also the possibility of hybrid systems incorporating OMEGA with satellites, inertial techniques and doppler radar.

An interesting British Paper outlined the concept of a chain of four ocean platforms moored across the North Atlantic. These would be about 400 ft. in length and shaped like giant mushrooms. About 300 ft. of the structure would be submerged, while the exposed area would contain most of the electronic and domestic equipment necessary to provide V.H.F. communications and secondary surveillance radar facilities.

The platforms would include a landing area for helicopters, and could be linked together either by submarine cables or by making use of communication satellites.

Another subject discussed in this session was the problem of world-wide time synchronization; space-tracking stations required a timing accuracy of about 5 microseconds between remote clocks.

The third session was concerned with satellite navigation systems. The only system fully implemented is the U.S. Navy system, the principles of which are now quite widely known.

It was interesting to hear that the original system concept in 1960 had been little changed, although the most underestimated problem at that time had been the geodetic uncertainty in the physical shape of the earth. Improvements in this one area alone had resulted in increased fix accuracy by about an order of magnitude from the earlier results of about one mile. At fixed-site locations, errors of a few tens of metres can now be realized, and provided own ship's velocity is known accurately it is possible to obtain a fix to within about 0·1 nautical mile when under way.

Three satellites will be maintained in orbit under the present programme, and these provide fixes at intervals of between 60 and 90 minutes depending on latitude.

Other Papers covered a variety of proposals and ideas for alternative or complementary navigation systems, for example, those based on hyperbolic techniques using synchronous earth satellites.

The final session produced a series of Papers on geodetic satellites and their use in establishing a world-wide datum system accurate to within ± 10 metres with respect to the centre of the earth. The close relationship between improved geodesy and improvements in long-range navigation was again apparent.

One Paper which appeared to be of great intrinsic merit described a complex mathematical technique in terms of vectors and matrices which was aimed at providing a unified approach to the error analysis of position finding systems. Some observers felt that this particular paper might have been more appropriate in a different forum, although it does serve to illustrate the wide scope of the topics which were discussed.

There are 13 member Nations of AGARD, and eight of these were represented, either as authors or observers, at the 14th Symposium. The U.S.A. contributed 17 Papers, four were from Germany, three from the U.K. and two from France.

Throughout this conference emphasis was placed on the problems created by increasing air traffic density across the Atlantic. Without exception, the methods proposed for improving aircraft control were all extremely costly, and would inevitably demand a large research and development effort.

The writer is of the opinion that the major lesson to be learned from this Symposium is the very urgent need to reach an international agreement on the optimum control, surveillance and navigation system to be adopted in the interests of all concerned. With the possible exception of the Americans, unilateral action is doomed to failure from a cost and effort point of view alone. A combined effort towards a standardized system is of paramount importance—and this system should be operational within the next decade.

PHILOSOPHY OF SCIENCE

Physics—A Theory

Lt. L. Matheson, R.A.N.

All theories procced on the basis of primary assumptions. The assumptions preceding this theory may bc reduced to a general statement, such as: " There is a fundamental harmony in the occurrence of natural phenomena ". Specific examples are Mayer's law of the conservation of energy, and Poincare's principle of relativity.

This is a fusion of what are thought to be two original theories. The first, a theory of universal immediacy, accords with Poincare's principle and appears to be well supported empirically. The second, a theory of the transformation of energy states, is rather more speculative. It accepts the principles of quantum mechanics, proposing, however, fundamental conceptual changes in spatio-temporal relationships and uses the first theory as a key. Thc two theories are brought together in a theory of energistic immediacy, which proposes a cosmological model.

It may be thought that an orientation such as that in paragraph 1 will lead to classical *(i.e.* deterministic) solutions. This is not so. Indeed, the vicw that mathematics alone represents a complete model is itsclf deterministic. But there is not harmony between relativity theory and quantum mechanics; an uneasy alliance is preserved at the expense of exactitude and is demonstrated in the masses of indeterminacics and probabilities of their mathematical treatment. " There is at present no satisfacory way of picturing the fundamental atomic (and sub-atomic) processes of nature in terms of time, space and causality." (Hoffman).

Universial Immediacy

Space is defined variously as:

(a) That which remains when matter is removed;

(b) The position-relationship possibilities of rigid bodies *(i.e.* " where ").

(c) A sort of natural order of the material objects of sense experience;

(d) That with which geometry is concerned.

These definitions treat space variously as a concept and as an objective absolute. The idea of space as an objective absolute is essentially pre-scientific, and retains such a character to-day only in terms of everyday, extra-scientific thought. The objective existence of space has never been shown empirically. The most efficient vacuum obtainable by experimcnt can still be shown to contain particles. Moreover, it has been shown that these particles interact with nothing (in the sense of that which cannot be detected) and accumulate other particles. Space cannot, therefore, be said to have validity as an objective absolute. If it is to have objective reality, it must be purely as a concept.

Few of our scientific concepts are grounded wholly in empirical science; most are products of our culture, our primitive senses, and common-sense rationalisation. So it is with space; it is such an all-pervading concept that it seems difficult to conceive of the universe, for example, other than in terms of matter and space. Hcre we see that space is a meaningful concept as a negative complement to matter. But the logically primary concept is the matter or, rather, material object, for it is this that has a basis in sense-experience. Space is a logical corrolary which enables us to ground the object in terms of position and rclations generally. Space may therefore be describcd with justification as arbitrary and, in its modern form, an intellectual abstraction that has its roots in Euclidean geometry.

Einstein showed in 1905, with the restricted theory of relativity, and again in 1915 with the general theory of relativity, that the classical concept of space was untenable. Similarly, the concept of the homogeneity of spacetime has proved to be somewhat in the nature of an expedient, much in the same manner as Bohr's electron orbits. Such an unsatisfactory history leads one to consider whether, indeed, the concept of space—no matter how modified—is of further use to science. It will readily be seen, however that its retention, even in its present, greatly modified form, is necessary in view of our concept of time.

Time is an example of the spectrum approach of classical thought: A spectrum consisting of past, present, and future—where " past " is, so to speak, the red end, " future " the violet end, and " now " the constant shift defined in terms of a unit rate. Here is Einstein's view of time:

" The physical time-concept answers to the time-concept of the extra-scientific mind. Now, the latter has its roots in the time-order of the experiences of the individual, and this order we must accept as something primarily given. One experiences the moment ' now ', or, expressed more accurately, the present sense-experience (Sinnen Erlebnis) combined with the recollection of (earlier) sense-experiences. That is why the sense-experience seems to form a series, namely the time-series indicated by ' earlier ' and ' later ', The experience-series is thought of as a one-dimensional continuum . . . The transition from this subjective time (*Ich Zeit*) to the time-concept of pre-scientific thought is connected with the formation of the idea that there is a real, external world independent of the subject. In this sense the (objective) event is made to correspond with the subjective experience. In the same sense there is attributed to the ' subjective ' time of the experience a ' time ' of the corresponding event . . . this process of objectification of time would encounter no difficulties were the time-order of the experiences corresponding to a series of external events the same for all individuals . . . The measurement of time is effected by means of clocks. A clock is a thing which automatically passes in succession through a (practically) equal series of events (period). The number of periods (clock-time) elapsed serves as a measure of time ".

Time is thus an objective phenomenon or it is not; Einstein says it is not. Time is relative to the individual observer and, following this line of thought, Einstein is led to reject the idea of objective simultaneity where the observers are separated in space.

However, that which is measured by clocks or radio-active decay is only that which is measured by clocks or radio-active decay. These depend for their operation on a base relative to which time is to be measured, exactly duplicating the Galilean base of motion—and this is significant. But they have no empirical validity unless we agree to call that time which we measure by these means. Thus time is seen to be a concept and our methods of measurement carry the implication of " beginning " as a logical corrolary, and motion, or passage, of time relative to a base. The notion of causality is also implied in the time order concept.

If that which we measure with clocks is time, objective simultaneity is, of course, an invalid assumption. Einstein has said that no concept exists for the physicist unless he is able to see it demonstrated in a particular case. We must therefore propose an experiment. Let N persons gather at, say, the Greenwich Observatory and let each be issued with a chronometer. These chronometers will have been tested to a pre-determined level of accuracy of mechanical motion. In any case, the limit of error would be such that we could satisfy a general requirement of synchrony of mechanical motion. Let these men go out and take up such a position that they are spread evenly throughout the world. And let two men enter separate space craft and be launched, in opposite directions, from the earth. When each man has taken up his position and the space craft have passed beyond the earth's gravitational field, let each man adjust his chronometer to allow for local variation, bearing in mind that these affect, not time, but the measuring system, so that mechanical synchrony is preserved.

Now let each man, after a previously agreed interval which is the same for all the men, measured from the time they left the observatory say " Now ! "—and note the time. It will be shown in all cases that the time noted in respect of "now" will be the same, even for the men in the space craft.

The principle of relativity states, in effect, that the phenomena of nature will be the same to any two observers who move with any uniform velocity whatever relative to one another. If we accept this principle then our current concept of time (and Einstein's) is invalid.

There is, however, an interesting point about this experiment which is immediately clear, namely, that what each of the observers measured was " now ". If the experiment is repeated in say, twenty-four hours, the observers will still measure " now ". They are not able to measure past or future in the same manner, nor will they be able to do so. Therefore, what clocks measure is not time.

It might be argued that the interval between the experiments shows a passage of time, or " now ". This is not so. Let us repeat (hypothetically) the

experiment without pause, again and again, for another twenty-four hours. Each experiment will produce the same " now ", which will be the same " now " for all. Bear in mind that we have not shown " past " or " future ", empirically—only " now ". We may not, therefore, posit them in a result. As empiricists we are bound to accept the evidence of the experiment and say that there is no empirical evidence for an objective " past " or " future ". The only objective reality is " now ". But " past " and " future ", merely by being thought, are valid subjective concepts.

It might be argued that the various " nows " experienced by the men are not simultaneous but coincident. We may illustrate that this is not the case by means of a pictorial analogy. Suppose Atlas, the ancient Greek God, really existed—and suppose that he grew tired of supporting the world on his shoulders. One day, passing an iceman's truck, he noticed a pair of the caliperlike tongs that icemen use to carry ice. Noting that the iceman was in a nearby house, he grabbed the tongs and fitted them around the earth, lifting it as though it were a block of ice. Was, then, the grip of the tong points as Atlas lifted the earth coincident or simultaneous ? We should say the latter, obviously, for both actions are causally dependent upon Atlas. Such is also the case with our hypothetical experiment.

This sundering of what has been considered an essential homogeneity may seem paradoxical. But let us first consider some of the consequences of our hypothetical experiment. If the only objective temporal reality is " now ", objective time is essentially timeless. It has not the property of motion, therefore no direction. We cannot detect any forces operating on it. If it has no direction but is, nevertheless, the same for any body of observers who move with any uniform velocity whatever relative to one another, it must be infinite in all directions. Objective time therefore, is absolute rest and is universally immediate. It contains within its essential nature all the properties formerly assigned to space. Therefore, a body at low velocity will be adequately defined in terms of time co-ordinates and we no longer need a concept of space.

Einstein's equation of the impossibility of (objective) simultaneity (Lorentz transformation) is then seen as an illustration of the mathematics of (subjective) duration relationships.

The Transformation of Energy States

The corpuscular nature of matter is now well-established in an empirical sense. Thus, when we speak of matter, we consider particles having the properties of rigid bodies. The idea of a body at rest is a concept corresponding to extra-scientific thought; *i.e.* primary rest is not shown empirically. But there is empirical evidence of motion, therefore particles have motion which we shall call primary motion. Now, motion implies space as a logical corrolary—and thus, time. If we declare our concepts of time and space to be invalid, we must re-define motion, which exists presently only in terms of spatio-temporal relations.

We speak now of a particle as existing in time; *i.e.* as having a certain duration. It comes into existence (*i.e.* is detected), endures for a certain period, in a certain direction or directions, observing that primary rest is not shown empirically, and then goes out of existence (*i.e.* is no longer detected). Seen as an event, the particle has a beginning and an end, a subjective past and a subjective future; had it the capacity for reflection, it would also be conscious of " now ". But its worldline is " now "; that is to say its beginning and its end, its past and its future, exist now, *i.e.* its worldline has a present, finite existence which corresponds exactly to the primary motion of the particle.

Therefore, a particle has the property of primary motion, which in turn has the property of duration. Thus, the duration of the particle, as a particle, is described in terms of the duration of its motion, and the primary motion of a particle is described adequately in terms of its duration in time. When it loses the property of duration it has lost the property of primary motion as a particle.

The properties "past" and "future" are properties of the duration of the particle. No matter in what direction the particle travels it is still, objectively, " now ".

By this means we provide a solution to the apparently paradoxical nature of the Feynman graphs. The essential paradox, *i.e.* the seeming penetration of the past by particles, is seen to be grounded in the assumption of an objective time spectrum for which there is no empirical foundation. Time passes, as the saying goes—but it is more accurate to say that particles move through time *i.e.* have a finite duration in time—but this duration is a property of the particle and not of time.

This also furnishes a possible explanation of a " postulate of impotence " (Whitehead's term): The Heisenberg principle of uncertainty. Uncertainty in the product of p and q, where p is momentum and q the ordinate of a particle, depends for its condition on the concept of time. If " now " is not a property of the duration of the particle then it cannot be posited in a calculation involving duration. The notion of location corresponds exactly to the subjective " now ", which is not demonstrated empirically. Location, therefore, is arbitrary and not a subjective reality. Any

attempt to calculate position as a property of duration must result in a Schrodinger *psi* effect; *i.e.* an average effect of location. Location may be predicted as a position-possibility in duration but may not be observed.

Consider particles having mass. Mass is defined by Newton as that property of a body which is exhibited by inertia; inertia is defined as the resistance of a body to a change of motion. But Einstein showed that, under certain conditions, energy and mass are mutually convertible. Let us consider mass as energy, bearing in mind that the conditions mentioned above represent limits, not of the equivalence of mass and energy, but of our ability empirically to achieve the transformation.

We said earlier that a particle has motion, a property of which was duration. We wish now to relate energy, mass, motion, and duration. Mass is a special case of energy which exhibits inertia; *i.e.* it seeks duration. Primary motion is the transformation function of the energy in particle state. Thus mass is a conservation function of the particle. If the resistance of a particle to a change of motion (*i.e.* its inertia) is proportional to its mass, we should find that the motion of a particle is proportional to its energy. But the energy of a particle is equivalent to its mass times the speed of light squared (*i.e.* $E.=MC^2$) in the equation of Einstein. Therefore matter is finite in duration and the concept of rest mass must be arbitrary and inaccurate.

Consider a particle in primary motion (*i.e.* in existence). Now, acceleration is shown empirically as a property of motion determined by environment; *i.e.* acceleration is an external force phenomenon. Therefore, let us consider for a moment, for the purpose of illustration, a particle freed of external influences; *i.e.* an ideal particle divorced from empiricism.

This particle will move with a uniform velocity of primary motion which, not being attributable to any external influence, must be due to the emission of energy. Therefore, the motion of this particle should be equivalent to a unit rate of emission in the following relation: $m=\frac{n\mathbf{h}}{E}$, where $\mathbf{h}$ is Planck's constant of action n is an integer, and E the energy of the particle.

But the emission of energy requires energy to overcome resistance to a change of duration. Therefore, the energy emission relation should be $m=\frac{n\mathbf{h}}{(E-w)}$, where $w=n\mathbf{h}$. So the residual energy in the particle on termination of duration should be in the relation: $E=(n\mathbf{h}-w)$ *i.e.* zero-point energy. This suggests that mass of a particle in primary motion will be a quantity in a simple diminishing series. Total duration, therefore, should be a simple harmonic progression in the final relation: $d=\frac{M-(n\mathbf{h}-w)}{MC^2}$

But if energy (*i.e.* $n\mathbf{h}-w$) passes out of existence, that is to say is no longer detected, we may not posit primary motion, or, therefore, duration. That is to say we may not posit *particular* duration as a property of such energy. Therefore it equals "now" in all respects and becomes immediate. Thus, it will be seen that laws governing the conservation of motion have relevance only to the duration of a particle.

But we cannot consider, empirically, a particle free of external influences. Therefore, let us consider the form of environment. We do not know the exact form of environment below the threshold of particle materialisation, therefore we postulate the (immediate) existence of fundamental energy in sub-particular units of Planck's quantum of action **h**. (See previous paragraphs.)

This of course, poses the question: which came first energy or matter? The question has been answered. If matter has not immediacy, but only the temporal quality of duration (*i.e.* finitude) then energy is the primary substance in virtue of its universal immediacy and Mayer's law of conservation.

The influence of environment is exerted on matter in terms of its effects; *i.e.*, by means of pressure. We speak now of positive and negative forces, although these are positive and negative aspects of a primary force (*i.e.* pressure). The forms of forces are essentially limited, although broad in their degree and specialisation of application.

The forms of force may be defined as follows:—

(a) Compression: *i.e.* forces which extend their pressure uniformly about an area of duration potential—or about a particle. But compression may also be caused by opposing pressures.

(b) Acceleration: *i.e.*, uni-directional pressure.

(c) Resistance: *i.e.* the negative complement of (a) and (b).

Given the sub-particular nature of energy we may propose a description of the creation of particles by compression. Now, there is a certain elasticity demonstrated in the compressibility of all (apparently) non-material substances, and also in their capacity for expansion to fill a (partial) vacuum. There is no reason, therefore, to suppose that the quantum h has not this property also.

We may suppose that energy in a normal state of immediacy is also in a normal state of equilibrium; *i.e.* zero-point equilibrium. So that energy in a state of immediacy, where zero-point equilibrium is a condition of the environment, is stable.

Suppose two events, *e.g.* two coincident particle flights, occurred in close proximity relative to one another. These events, we should expect, would disturb this equilibrium, causing:

(a) Local expansion; *i.e.* converging " bow-wave " effects; and
(b) Local friction which in turn would create heat, causing further expansion.

We should expect that these coincident effects, as they spread, would eventually meet, causing compression. At a certain point, which we shall call the critical point of compression, quanta would merge and form a particle, or particles. The intensity of this compression, and therefore the mass of the particle, would be proportional to the velocity of expansion. The particle, no longer in a state of immediacy but in a state of duration, would then move in the line of least resistance.

We have considered an ideal particle freed of external influences. It will be seen, however, that freedom from influence (*i.e.* a reduction of the intensity of environmental pressure) itself constitutes an influence on the duration of the particle.

If the resistance of a particle to a change of duration is proportional to its mass removal or significant lessening, of the force occasioning the resistance will have measurable effect on the mass of the particle—and therefore on its energy and primary motion. This disproportion would be adjusted by an increase in the velocity of primary motion, with a consequent decrease in duration.

If the force producing resistance is lessened sufficiently, the energy dissipated in acceleration will be emitted in quantities which will themselves constitute particles, though of lesser mass and, therefore, duration. Now, when we reduce the intensity of environmental pressure (*e.g.* in attempting to produce a vacuum) this is all we do; *i.e.* we do not create empty space. The volume of sub-particular energy will remain the same, although its density is reduced.

Thus, the **h** quanta would be in a state of tension due to expansion. With the primary particle emitting energy in particle quantities, we should expect to see a type of chain reaction with the creation of many smaller particles (probably of extremely limited duration). This may provide an explanation of the phenomenon mentioned earlier.

Thus we see that external environmental forces, to maintain immediacy, must be in the condition which we called zero-point equilibrium. Disequilibrium will be mathematically positive and negative in character, although negative disequilibrium will have positive, measurable effects on a particle; *i.e.* positive and negative disequilibrium should display mathematical properties.

We have considered acceleration seen as a consequence of negative disequilibrium. It was there seen as an intensification of the transformation function of the energy state. Let us now consider acceleration as an environmental pressure; *i.e.* a particle subjected to secondary or superimposed motion.

Now acceleration imposes on a particle an increase in velocity. But we know that the mass of a particle increases in proportion to the increase of velocity, becoming infinite at the speed of light (relativistic law connecting mass with velocity). Thus, superimposed or secondary motion is a conservative force which increases mass and therefore extends duration. This in effect supports the description above concerning the creation of matter by compression. It furnishes a possible explanation, at least, of the existence of cosmic ray particles.

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DEFENCE RESEARCH ESTABLISHMENT, PACIFIC

R. F. Chinnick, B.Sc., M.Sc., P.Eng.
Director General

The Defence Research Establishment Pacific (DREP) is one of the eight laboratories operated by the Defence Research Board. Previously known as the Pacific Naval Laboratory (PNL) the change in nomenclature was formalized in July 1967, in order to more clearly indicate its relationship to DRB, its geographic location, and its involvement with military research for all functions of the Canadian Forces, including maritime, land and aerospace activities.

The Establishment is the most westerly laboratory of the Defence Research Board and is located within HMC Dockyard at Esquimalt, approximately three miles from the centre of Victoria, British Columbia. It was initiated in 1948 and for a few years utilized temporary buildings loaned by the RCN. In 1954 it acquired its own buildings, to which extensions and additions have been added over the years, until at the present time it comprises approximately 50,000 square feet of laboratory and office space, housing slightly over 100 research scientists, service officers and technical and administrative support staff.

In addition to the laboratory facilities, DREP has two research vessels, the *Endeavour* and the *Laymore*, from which various field activities are conducted. Furthermore, certain projects which require the support of aircraft, additional vessels, or other vehicles are catered to by arrangement with the appropriate branch of the Canadian Forces, or other Government departments.

Historically, the laboratory has been principally involved with problems associated with the naval branch of the Forces. A major contribution has been made, and continues to be made in the area of support to naval military problems.

Materials Research

Research and development continues in methods and techniques of reducing or eliminating corrosion, improving paint performance, analyzing boiler and machinery difficulties and recommending solutions.

Several examples of research activities may be given. One in particular is recalled since the work has been reported in this journal[1]. This is the hydrogen peroxide method of removing vanadium-rich deposits on superheater tubes. The problem occurs when bunker oil containing vanadium compounds is burned. The result is that the sticky combustion products produce a build-up of slag-like deposits on the superheater tubes with a consequent loss of heat transfer efficiency and, if not corrected, the ultimate failure of the superheater tubes. Numerous techniques for the removal of the slag have been employed. The most effective is the method developed at this laboratory, employing applications of hydrogen peroxide solution with a reasonable soak period, followed by washing using jets of water to remove the residue, which is now in the form of finely divided particles.

More recently another development has taken place at DREP, and may prove to be of some interest to the reader. This is a technique for evaluating the wear in boiler tubes using a nuclear gauge. In essence, the wall thickness of the tubes under evaluation is determined by passing through the tube a radioactive source and simultaneously moving a geiger counter detector along the outside of the tube. The wall thickness is determined by the "counts" obtained for a given time interval. Variation in wall thickness may be detected to

the order of 0·005 in. in a tube with a nominal wall thickness of 0·100 in. The advantage lies in the non destructive nature of the procedure. Preliminary evaluation of this technique has been encouraging.

Another study, which has been under way for some time [2] is producing very promising results. This is the technique of using spectrometric analysis of lubricants to determine machinery wear. Typical metals which may be found in lubricants as a result of various types of wear (bearings, rings, *etc.*) are iron, copper, silver, nickel, chromium, manganese, *etc.*, and these may be measured with ease to a few parts per million in a sample of lubricant. By establishing a "normal" contaminant level in any given lubricant, it is a relatively simple matter to detect abnormal wear in any machine when a particular element begins to show increasing concentration in subsequent tests, made on a regular basis. This permits ample warning of incipient failure, only assuming that the testing process can be conducted expeditiously and the results of the tests relayed in adequate time to the appropriate agency. The time required to carry out the analysis of a given sample is quite short, of the order of two minutes. However, the time required to obtain the sample from a particular machine, transport it to the laboratory, evaluate the record and return a report to the appropriate authority is presently a matter of days. While this delay is acceptable for many equipments, due to the long lead time of warning inherent in the technique, there will be cases where the sample interval is such that wear has occurred to a significant level, and a very fast response is required. This is particularly relevant for very high r.p.m. engines such as are employed in aircraft and certain other military equipment. A typical spectogram of a lubricant from a naval ship is shown in Fig. 1. At the present time, and on a pilot basis, DREP is evaluating over 200 lubricant samples per month for the Canadian Forces.

Anti-Submarine Warfare Research

Turning to ASW activities and the submarine-detection system environment, the problems experienced are similar in nature to those encountered by every laboratory engaged in such activities. Numerous projects are under way at DREP aimed at improving or predicting the range and reliability of detection methods. The majority of the studies are aimed at improving the available knowledge of the physics of the problem, particularly a thorough evaluation of the environmental parameters of the North East Pacific and the Arctic Oceans. Several examples covering work in progress can be reported.

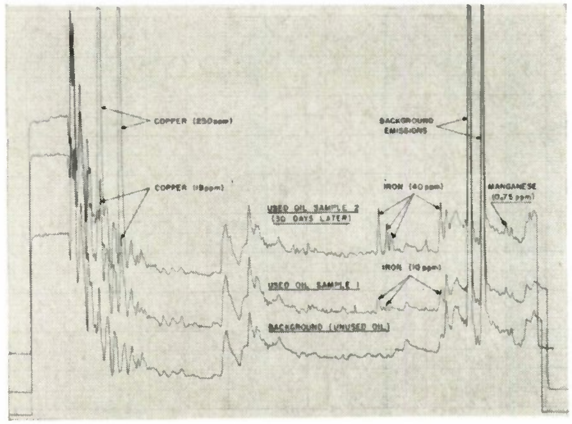

FIG. 1. Spectrometric Analysis of Lubricating Oil from a Low Pressure Compressor, showing the development of metallic contamination in a one month period. (This series of measurements suggests that a failure is imminent.)

Ocean Acoustics

It is well known that with any sonar system, the ocean acts both as a transmission medium and as a source of interference. The interference may result from several effects, one of which can be classed as surface reverberation. In this category the reverberation, or backscattered sound, is a function of surface roughness, angle of incidence and perhaps other parameters. It is desirable to understand these effects sufficiently well that a family of curves may be prepared to establish the characteristics of such phenomena under a wide variety of conditions. Although surface reverberation was much studied in the early 1950's, interest has arisen again in recent years, particularly because of the need for information at the low frequencies used in modern detection systems. It has been found that an objective measure of "sea state" is essential if reverberations are to be

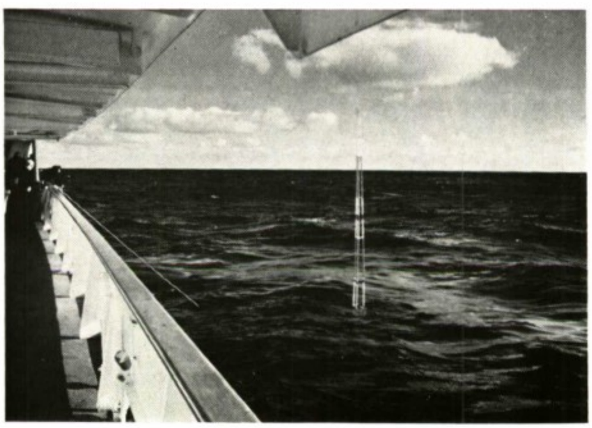

FIG. 2. Photograph of a wave pole, taken from the deck of "Endeavour".

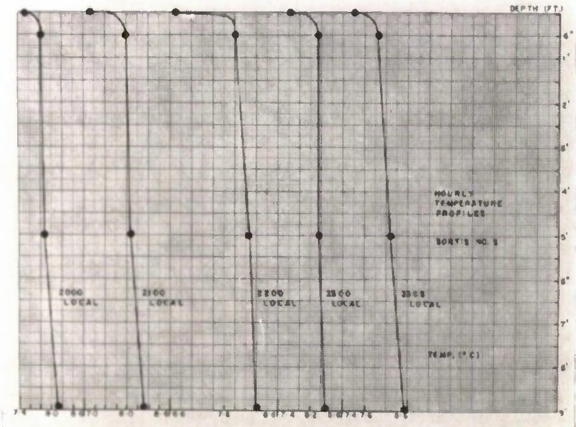

FIG. 3. A sequence of measurements taken during a period of surface cooling.

related to wave conditions and considerable effort has been put into the development of a wave pole (Fig. 2) and an accelerometer float, either of which can be used to measure the wave spectrum.

Similar activities are envisaged for the evaluation of volume reverberation in the Pacific. Volume reverberation is similar to surface reverberation in the sense that this term also describes the sonar echoes produced by the environment—in this case the reflecting material (usually of biological form) is often concentrated in layers at depths of tens to hundreds of metres below the surface. Observations in the Atlantic and Mediterranean have shown that the level of volume reverberation depends upon frequency and that the spectrum of reverberations from a broad band source contains peaks which are presumed to be due to resonance of the bladders of marine organisms. The spectra are found to vary with geographical location and work is underway to determine the nature of volume reverberation in the North East Pacific.

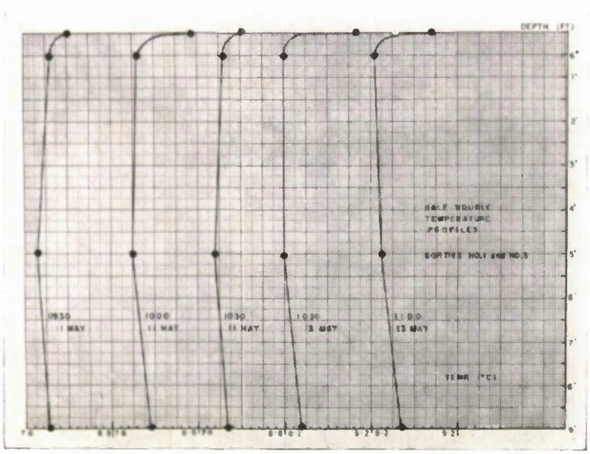

FIG. 4. A sequence of measurements taken during a period of surface warming.

The reverberation work is closely co-ordinated with similar and more extensive work [3] at the Defence Research Establishment Atlantic (formerly Naval Research Establishment) as it is considered essential that the two laboratories be in a position to express this information in consistent terms for use by Canadian and Allied Forces.

Experiments are just beginning to investigate the acoustic characteristics of the sea surface sound channel which is found over much of the sub-arctic Pacific for most of the year.

Surface Temperature Measurements

Returning to ocean surface parameters, a study has been completed [5] on the relation of temperatures at the very surface of the ocean with respect to temperatures taken at depths of one to ten feet. This study originated as a result of a requirement to determine the reliability and suitability of air-borne radiation thermometer (ART) measurements, using an infra-red detector and measuring the ocean surface radiation temperature in the 8 to 14 micron atmospheric window.

The results of the tests indicate that differences as large as $\pm 1{\cdot}6$°C exist between measurements with an ART and conventional temperature measurements taken from ships. In general, the readings from the ART are higher during the day-time heating period, and lower during the night-time cooling phase. The explanation is that the ART measures the temperature of a very thin layer of the water surface (less than 1/10 in.) whereas bucket temperatures or intake water temperatures are sampling water at comparatively greater depths. Two graphs, Figs. 3 and 4, are shown which illustrate this effect.

Under Ice Acoustics

Much of Canada's coastline faces ice covered waters for a major portion of the year and it has been clearly shown that modern submarines can operate freely in these regions. Considerable effort has been expended by DREP in studying sound propagation, reverberation and ambient noise under Arctic ice.

Measurements have shown that the surface duct often exhibits a very pronounced upward refraction, and propagation characteristics which may vary from excellent to terrible, depending upon the roughness of the under surface of the ice. Reverberations are similarly dependent on ice roughness.

Ambient noise is very different from that in the open sea. The major causes are cracking of the brittle ice surface when the air temperature is cold and decreasing, and the effects of wind blowing over the rough ice surface. Another noise source

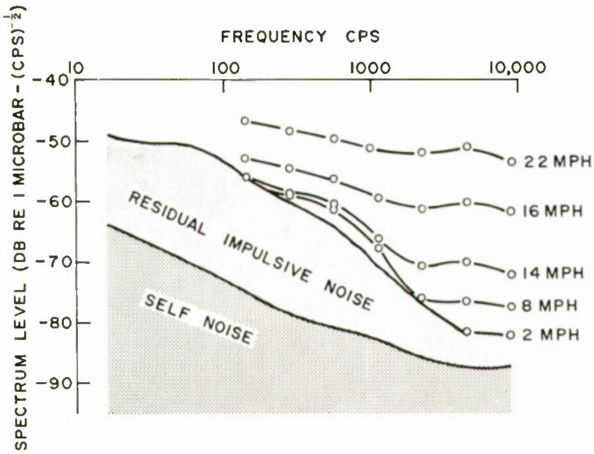

FIG. 5. Pressure spectra of wind generated noise, as a function of wind speed.

is the movement of broken ice. Existing data obtained by DREP indicates that the noise spectra may vary as indicated in Figs. 5 and 6 (4, 5). All of these effects have a strong seasonal dependence. Access to the area is very difficult at the best of times and it is particularly so during the spring and autumn when the ice is breaking up or forming. In order to obtain noise data for these periods, five automatic noise recording stations are presently (Summer 1967) in transit to the Arctic. These will be deposited on the sea bed in five locations and will record noise spectra once per hour for a twelve month period. If they are successfully recovered in the summer of 1968 they will provide much of the missing data.

Turbulence and Internal Waves

Many of the problems in ASW have lead research workers to the point where they are unable to go further with the familiar assumption that the ocean is a simple horizontally stratified medium. In fact the ocean is full of turbulence and internal waves and there is growing evidence to suggest that there are variations of water properties in all spatial scales of a much more static nature. Very little is known about these phenomena, yet they are a significant part of any description of the medium in which submarines operate.

The Fluid Dynamics Group is occupied with the study of the distribution and dynamics of these small scale, high frequency fluctuations and is concerned with ways in which a submarine may modify its environment (e.g. by the generation of turbulence or internal waves).

During the past ten years this group has discovered the form of the spectra of velocity and temperature fluctuations in ocean turbulence and has studied the distribution of turbulence in the ocean. It is expected that the description of the temperature structure in spectral terms will assist in the problem of understanding the scattering of sound. It has been shown that under storm conditions the ocean is everywhere turbulent above the thermocline and that there are patches of turbulence in and below the thermocline. The cause and life history of these patches is still obscure but they provide the first physical evidence for the large eddy viscosity which has had to be assumed to explain heat transport in the thermocline.

Internal waves are being studied in the Strait of Georgia where particular attention is being paid to the interaction between these waves and surface waves.

Low Frequency Electromagnetics

A number of investigations are underway in this discipline. One activity is particularly related to the localization of submarines by magnetic anomaly detection (MAD). With the advent of optically pumped magnetometers utilizing electron resonance in rubidium or caesium vapour or helium, the inherent sensitivity of future MAD equipment is potentially very much enhanced, provided the ambient magnetic noise detected by such high sensitivity equipment can be sufficiently reduced. One source of such noise is the natural magnetic background variation, in particular those oscillations known as micropulsations. These are small variations (see Figs. 7 and 8) in the earth's magnetic field produced by perturbations of the solar wind interacting with the earth's magnetosphere. Micropulsations are of interest also to

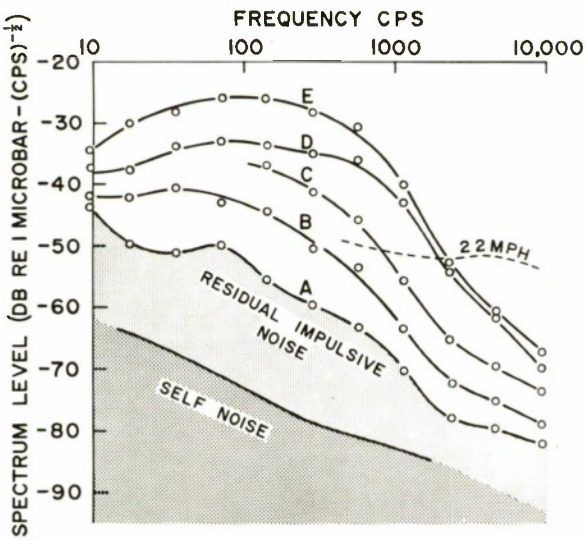

FIG. 6. Pressure spectra of thermally generated noise. Curves A, B, C, D and E reflect different conditions of the surface ice with respect to temperature, rate of change of temperature, and the vertical temperature profile in the sea ice. The data covers a 15 day period in February 1964.

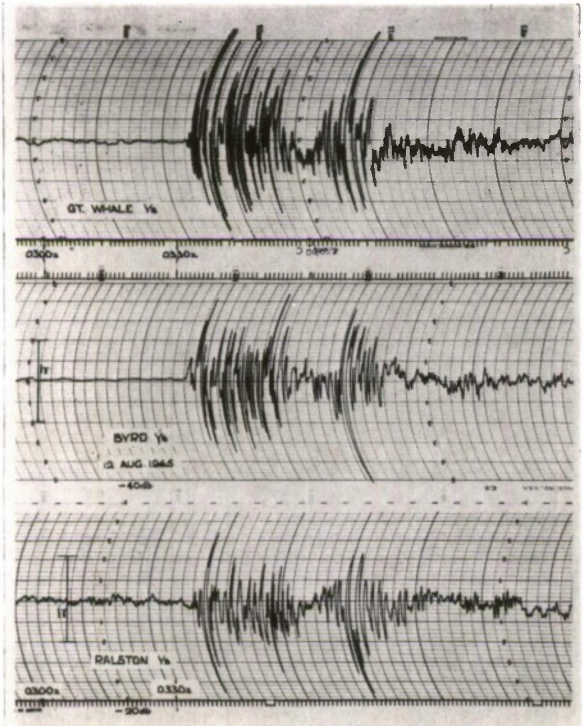

FIG. 7. Micropulsation activity at Great Whale, Byrd, and Ralston, Alta. illustrating a high degree of similarity.

geophysicists engaged in a variety of research problems related to the solar wind, including aurora, ionospheric disturbances and other upper atmospheric phenomena.

Returning to the specific military application of the study at DREP, it is desired to establish a synoptic appreciation of the activity of micropulsations as a function of daily, monthly, yearly and solar cycle activity. In addition it is desirable to analyze the structure of the micropulsation activity, and determine the phase and amplitude coherence of the structure at various geographic areas [6, 7].

To collect some of the necessary data for the programme, this laboratory has established, in co-operation with the University of British Columbia and other agencies, a series of monitor stations. These are located at Great Whale River, P.Q., Mont St. Hilaire, P.Q., Ralston, Alta., Westham Island, B.C., and Byrd, Antarctica. Initially, these stations were equipped with recording equipment providing a visual chart record only. More recently, appropriate slow speed tape recorders have been installed at some of the monitor stations and ultimately all will have this facility. The addition of tape recording equipment makes readily feasible the recall and analysis of data by electronic and computer data processing techniques. Other refinements which have been designed for the field equipment include selective band pass filters, automatic gain switching and internal calibration facilities.

In addition to the permanent monitor stations noted above, mobile stations have been deployed in the Arctic Ocean, on the West Coast of Canada, and in the Bahamas. In some of these exercises data were recorded simultaneously on the land, in the sea and in the air. Here again the objective is

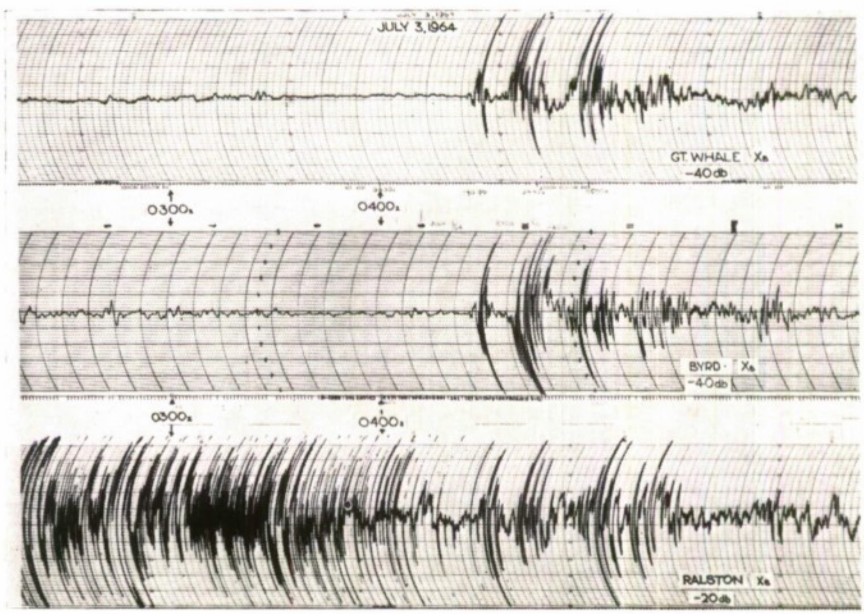

FIG. 8. Micropulsation activity at the same stations as noted for FIG. 7, but showing an example of lack of similarity.

to determine the degree of coherence between the micropulsations recorded at the various sites. It is from these data, and the data obtained at the permanently located stations, that the necessary material is being obtained which will determine the feasibility of neutralising micropulsation activity as a background interference in future MAD equipment.

As a result of these experiments a new type of interference has been detected and is in the process of being investigated. This may be called " swell noise " and is in fact a magnetic signal created by the motion of the long period waves or swell of the ocean. Since sea water is a relatively good electrical conductor, ocean waves moving in the earth's magnetic field induce eddy currents within themselves, which in turn produce varying magnetic fields. As the amplitude of these fields varies with wave length as well as wave height, that due to the long waves of ocean swell becomes most important. A theoretical model has been developed to estimate this effect for typical swell, and the results of this study are shown in Fig. 9. Experimental evidence is being collected to compare with the theoretical model. Further details on the curves shown in Fig. 9 may be obtained from Reference 8.

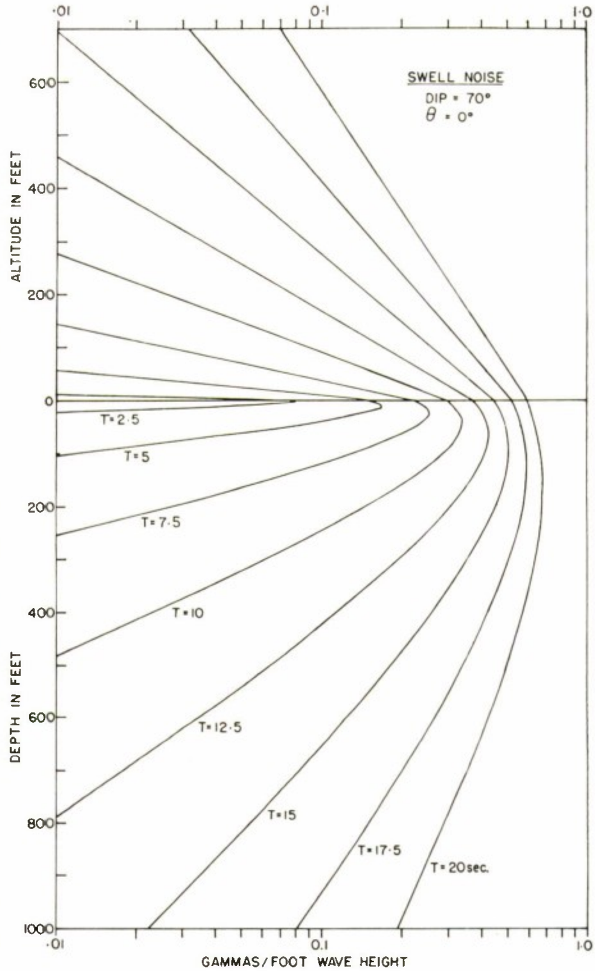

FIG. 9. Theoretical curves illustrating the effect of swell or wave height on the Induced Magnetic Field. T is the period of the wave in seconds and θ is the eastward inclination of the direction of wave propagation from the magnetic meridian.

Summary

The selected samples given above are typical of the overall programme underway at DREP. A considerable degree of credit for the various accomplishments of each study is due to the excellent support available both within and outside of the establishment. In house the availability of trained and experienced specialists in numerous fields (mathematics, physics, chemistry, engineering, computer techniques and military research) has ensured an efficient series of studies and projects. In particular the ability to call on specialist assistance from other DRB establishments, universities and numerous scientific and military agencies has permitted what is believed to be a productive contribution to military science.

Acknowledgement

Permission of the Chairman of the Defence Research Board to publish this article is gratefully acknowledged.

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THE 4th INTERNATIONAL MASS SPECTROMETRY CONFERENCE

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Bragg Laboratory

Introduction

This conference was held in West Berlin from the 25th-29th September and was organised jointly by A.G. Massenspektoskopie der D.P.G. (Germany), A.S.T.M. Committee E.14 (U.S.A.), G.A.M.S. (France) and the Hydrocarbon Research Group of the Institute of Petroleum. The conference was attended by approximately 500 participants from 19 countries, representing an increase in attendance which followed the trend established by the three previous conferences.

The number of papers presented showed an increase over those at previous conferences but as before all the uses of mass spectrometry could not be covered.

During the week, 16 review papers and 96 communications were presented. No discussion time was allotted after the review papers but a short time was available after all the communication papers. In nearly all cases this opportunity was well utilized, the questions often being curtailed due to lack of time.

Papers Presented at the Conference

The programme was divided into sections, some occupying more than one session. The divisions were as follows:—

(a) *Data Acquisition and Processing*
The papers presented in this session described the type of information received from a mass spectrometer and the methods available for presentation to a computer. As can be seen from the sessions of a similar theme below, this topic covered a wide range. The emphasis, in this session, was placed on using the computer to reduce the amount of information fed into the memory and store of the computer whilst still leaving sufficient for an analysis of the fragmentation pattern received. Systems for slow, fast, low and high resolution work were described.

(b) *Mass Spectrometry of Organic Compounds*
This was the major topic of the conference, taking four sessions and comprised of three review papers and 26 communications. The range of work covered in these sessions was so vast that a brief summary is impossible. Any organic chemist was bound to find some of the papers of direct interest. These were the sessions where the discussions were most lively, as in many cases the authors of the papers quoted were present and points of dispute and experimental technique were debated.

(c) *Data Acquisition and Instrumentation*
This session covered "hardware" rather than samples and results. The design and improvement of computer systems to suit particular needs were discussed. Mass spectrometers received similar treatment to attain conditions giving higher resolution, greater stability *etc.*

(d) *Ion-Molecule Reactions*
Six communications were presented on this topic. The papers varied but the main interest lay in the kinetics and mechanisms of ion molecule reactions and the types of sources that could be used for various reactions.

(e) *Inorganic Quantitative Analysis*
The bias of the papers was to spark source techniques. Ion beam chopping was proposed as a technique for increasing reproducibility through the increased consumption of sample, reducing errors due to inhomogenity of sample. The problems of good detection systems were again considered, improvements being suggested both in the conventional photographic plate technique and also by using electrical detection where the number of considered elements was small.

The use of ion impact sources and lasers to ionize the sample were discussed. Two specific papers were presented, one on the study of the thermodynamics of sulphur and selenium vapours using electro-chemical Knudsen cells and the other on a small mass spectrometer designed for the isotopic analysis of oxygen in water.

(f) *Instrumentation and Data Processing*
The twelve communications presented in this session had a similar theme to those in session (c), *i.e.* machine improvements and automation of results.

(g) *Theory of Mass Spectrometry*
The main interest lay in the different techniques used to calculate ionization potentials. A review paper covered the range of techniques, whilst a presented paper discussed the use of Gaussian atomic orbitals with respect to this problem. Papers were also presented on ionization curves, use of photo-electrons, Franck-Condon-Factors and dissociation processes.

(h) *Chemical Ionization*
A review paper was presented entitled "Chemical Ionization Mass Spectrometry".

(i) *Elementary Processes*
Papers given in the two sessions on this topic varied widely, ranging from ionization processes to meta stable transitions and molecular orbital calculations.

(j) *Photon Impact*
Interest in this field has increased in the last few years and is now finding many uses. The two review papers presented indicated that the interest would be much greater at the next conference in this series. Two papers were given, one of a specific nature, the other describing the application of photo-ionization to small polyatomic molecules.

(k) *Field Ionization Mass Spectrometry*
Although field ionization was first reported in 1954 it is only since 1960 that uses of this technique have been widely investigated. The basic source types—point, thin wire and fine edge (razor blade) are still used but the differences between them more fully understood. The advantages and disadvantages of each type were both described in the papers and discussed to the limit of the time allowed. The difficulty of exactly reproducing the sources leads to poor sensitivity and reproducibility for analytical applications but suggestions were put forward to reduce these errors and make this an acceptable technique.

(l) *Space Mass Spectrometry*
One review paper was presented under this heading and described the problems of sampling, machine reliability and the physical size and weight of spectrometers and ancillary equipment. The problems peculiar to machine function in space were also described. The continual effort to reduce size and weight of spectrometers was clearly illustrated and a brief history given showing the progress made to the very small spectrometers at present in orbit.

(m) *Nuclear Physics*
The various methods for rapidly obtaining a sample from a nuclear reactor, when required, were discussed as well as the application of mass spectrometry to specific problems.

Conclusion

The increasing importance of mass spectrometry both in research and as an analytical tool was clearly established. The initial use of mass spectrometers for isotope separation and analysis of isotopic abundances now seems to be submerged beneath the applications to organic chemistry. Well over half the conference concerned organic chemistry, the complexity of fragmentation patterns being such that computers are applied mainly to resolving spectra from organic molecules.

Many participants agreed that the large attendance tended to decrease rather than increase the opportunities for personal contact.

The proceedings of the three previous conferences have ultimately been published as books, containing both papers with discussions and a comprehensive bibliography. The corresponding book of this conference is expected to be published this year and should be of interest and use to all mass spectroscopists, but, in particular to those in the field of organic chemistry.

SCIENTIFIC AND TECHNOLOGICAL PROBLEMS IN UNDERSEA WARFARE

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Admiralty Underwater Weapons Establishment

SUMMARY

The scientific and technical problems encountered in the development of new equipment for use in underwater warfare are described in broad terms. The field covered includes sonar, torpedoes and mine warfare, and concludes with a very brief analysis of the problem of design optimisation of an anti-submarine weapon system by listing the parameters that can influence the choice of such a system.

Introduction

Some 70% of the earth is covered by sea and open to our ships. Furthermore, the sea surface provides a convenient interface to the air, water and land. However, surface ships are now threatened by superbly armed submarines, which are fast and silent, which have snorts and possibly nuclear propulsion to make them almost independent of the surface and of the sea state—and whose number, capability and proliferation amongst the nations of the world are incomparably greater than ever before.

We therefore must develop, in an economic manner, an *anti-submarine* capability to match the submarine threat of potential enemies. Conversely, we must develop the detection, communication and weapon capabilities of our own submarines, to match their increased performance and their correspondingly increased tasks.

We also must retain our offensive and defensive capability in the deadly and subtle field of mine-warfare. Mining is still one of the cheapest ways of imperilling shipping in confined, shallow waters.

Finally, in *deterrence,* the oceans in their enormous extent and depth, offer unsurpassed scope for the concealment and protection of long-range weapon launchers, and pose the challenge of discovering, anticipating and countering possible means of limiting these advantages.

These various fields of undersea warfare share the need to generate, propagate and process signals passing through sea water, and to propel and guide weapons in that medium.

Many of the problems and techniques involved are rather specialized, and there is little knowledge or interest in this field outside the Navy's own establishments. Since it may take as much as fifteen years from the start of research to effective operational service of a weapon system, and say a further fifteen years before the resultant equipment is phased out, we must maintain a vigorous, balanced and forward-loking research programme to give us a flying start in meeting the needs of the Service.

This paper will therefore outline some of the problems to be faced in the development of sonar, underwater guided weapons and mine warfare.

COMPARISONS BETWEEN SONAR AND RADAR

By far the most effective technique of underwater detection is still the acoustic one, known as sonar. It is instructive to compare this with the above-water electro-magnetic technique of radar:

Speed-of-Sound Problems

The speed of sonar radiation is roughly 5,000 ft. per sec., as compared with 1,000 million ft. per sec. for radar. Hence, if we send out a sonar pulse (known as a "ping") in a given direction, we must wait for a minute, to receive echoes from a mere 25 nautical miles, and a 12° beam would take half an hour to sweep 360°, getting back just one echo pulse per beamwidth. Thus we have no option but to use—and watch—sonar beams of many discrete bearings at the same time, and to minimize the interactions between them.

A vehicle speed of 30 knots is 1% of the speed of the sonar wave. This compares with radar, where 600 knots represents only one millionth of the speed radio waves. Thus the relative movement of the sonar vehicle and its target may compress or stretch the received echo wave-form by several per cent, rather like a gramophone record played at an incorrect and varying speed. Hence the "Doppler" effect, which is insignificant or marginal in radar, is dominant in sonar. Velocity-discrimination which in radar is normally difficult to achieve, can rarely be ignored in sonar.

For a single, unmodulated pulse, the Doppler velocity resolution is approximately

$$\Delta V = c^2/(4 \quad \Delta R f)$$

where c is the velocity of sound in water, ΔR is the range resolution implied in the pulse-length, f is the frequency.

Thus, for example, a pulse length equivalent to a 25 ft. range resolution and a frequency of 5 kc/s would imply a velocity resolution of 30 knots—which is of little practical value for sea-borne craft. On the other hand, a pulse length equivalent to a 250 ft. range resolution and a frequency of 15 kc/s would give a velocity resolution of 1 knot.

For efficient "matched-filter" reception, this fine velocity resolution implies the *neccesity*, as well as the opportunity, of distinguishing multiple velocity channels for each discrete directional sonar beam. Furthermore, the Doppler effect due to own movement varies with direction, from plus own speed when approaching an object dead ahead, *via* zero, looking sideways or up and down, to minus own speed when steaming away from an object astern. The appropriate corrections must therefore be inserted into all bearing/Doppler receiving channels. This is achieved by a device known as "Own Doppler Nullifier" (ODN). Referring to Fig. 1, if we have transmitted n cycles of sound in time T1, the pitch of the signal received by the moving ship is n/T2; the purpose of the ODN is to alter the pitch to n/T3 so that it is indicative of target movement only.

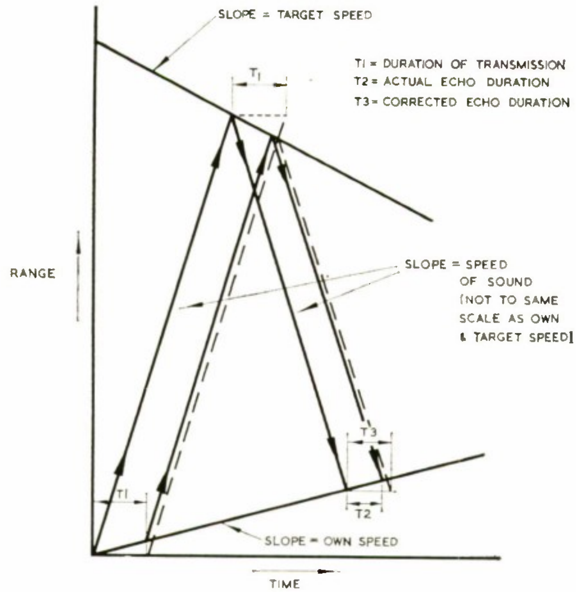

FIG. 1. Diagram illustrating Doppler effect for moving source and target.

Transducer Array Problems

In sonar, the requirements of sensitivity and angular discrimination lead to transducer arrays of dimensions comparable with the width of the ship. There are then challenging hydrodynamic problems in marrying such transducer systems with the hull design.

When a sonar array has been designed for all-round cover, there are further problems in bringing the constituent transducers jointly to bear on a given direction. This requires, for each direction, delay devices, so that a plane wave-front, impinging on different transducer elements at different times, will produce coincident output signals (see Fig. 2).

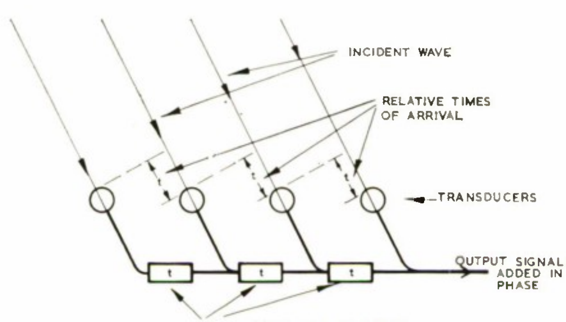

FIG. 2. Application of delay lines to eliminate effect of wave-front approaching at an angle.

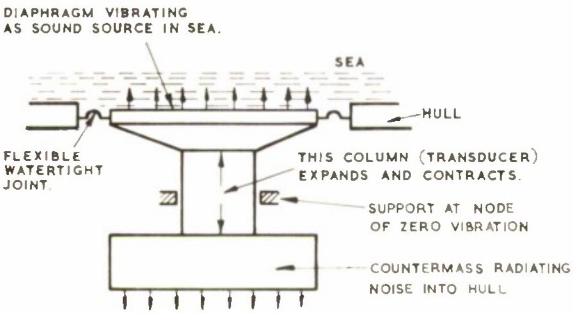

FIG. 3. Typical arrangement of transducer.

These beam-steering delays may be comparable to the sonar's pulse-length (or equivalent " compressed " pulse length). This situation—as well as the wide Doppler bandwidth—will normally preclude the use of simple phase shift elements (which ignore integral numbers of r.f. cycles in the delay), or of dispersive elements controlling phase by changing frequency, either of which can frequently be used in radar or lieu of full-length, wide-band delay devices.

Transducer Problems

A sonar transducer is a piece of material which changes its dimensions, when subjected to an electric or magnetic field. With an alternating excitation, it will therefore produce an oscillatory drive to a piston. Vibration within this piston can make it difficult to keep all its working face oscillating in step, and there are much more severe problems in keeping a large array of inter-acting transducers all in step.

A transducer must normally exert its force between a working face in the water and a countermass at the other end. But the countermass will also oscillate—and so generate sound waves, and it can be quite difficult to keep this sound from interfering with the desired acoustic radiation, or from causing interference or habitability problems inside the ship (see Fig. 3).

Limitation in Power

Sound is transmitted by alternate compression and tension in the medium. In a liquid, if the magnitude of the tension exceeds the ambient (absolute) pressure, bubbles of vapour are created and hence further sound transmission is obstructed. This is one example of the phenomenon known as *cavitation.*

We must therefore restrict the acceleration of the transducer face to a level which will not result in cavitation. To transmit pulses of high sound energy, it is therefore necessary to spread the energy in space, over a large transducer array, and to distribute it in time, over a long pulse.

Pulse Compressions etc.

However, the tail end of, say, a one-second pulse would be entering the water, when the leading edge has already advanced 5000 ft. The range discrimination would therefore be limited by the pulse length, were it not for the use of sophisticated techniques, " labelling " the different parts of the pulse by distinctive modulations. In ultra high-power radar, there is now a similar peak-power problem, and this has been countered by the same technique of " pulse stretching and re-compression ". In fact, satellites and ballistic missiles brought the radar designer face to face with problems of data-rate, Doppler spread, array design and peak power, similar to those with which the sonar designer has been contending for many years.

NOISE AND REVERBERATION

Thermal Noise

The sensivity of all receiving systems is limited by " noise ". Heat, which is basically the kinetic energy associated with rapid, random movements of molecules, atoms and sub-atomic particles, generates acoustic noise by the movement of molecules in the water, just as the thermal energy of electrons and ions, in the space observed by an aerial, produces electro-magnetic noise.

A radar's sensitivity is indeed limited either by this effect or by the random thermal movement of electrons in the input stages of its own *receiver.* However, before these effects become significant, sonar usually has to face a whole gamut of noise troubles of its own:—

Other Noise

The sources of noise affecting sonar include breaking waves, noises made by various forms of marine life—including, believe it or not, fish—and interference from other sonar, both directly and *via* intermediate scatterers. To obtain an acceptable data rate, any search sonars must " insonify " and observe much or all of its angular coverage in parallel; hence the directivity patterns are unlikely to do much to limit mutual interference between sonars in company.

Own Ship's Noise

Own ship's " *radiated noise* " may actuate a mine, or allow an enemy torpedo to home, or it may be picked up by enemy listening gear. However, it may also be scattered back, from the surface or bottom, or from the volume of the sea, into the ship's own receiving system. Other interfering " *self noise* " may be conducted acoustically through the air in the ship, or within the structure of the hull, into the sonar's receiving transducers.

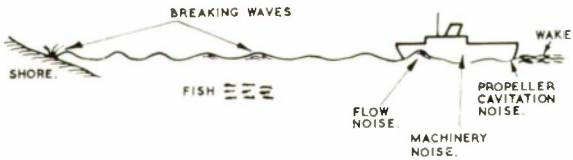

FIG. 4. Sources of noise.

Own ship's noise may be of hydrodynamic origin, due to the regular—but turbulent—flow of water past the hull plates, or due to the random ship motion to which some of our stomachs are so sensitive. It may also be due to the bow-wave breaking, to the pressure fluctuations produced by the propellers, or to the collapse of cavitation bubbles at the forward face of the propeller. (After all, a propeller must produce high pressure behind, and low pressure in front of it. The low pressure is likely to lead to cavitation, but the resulting bubbles of near-vacuum collapse violently, when exposed to the ambient pressure.)

Other noise sources include a ship's propulsion and generating machinery, gears and pumps (see Fig. 4).

It is a major research problem to elucidate the mechanisms producing noise, and to investigate techniques for suppressing or isolating it—or altering its spectral distribution.

Reverberation

Until quite recently, it was assumed that it is always noise that limits a sonar's performance. Now we know that the noise is frequently swamped by the back-scatter of our *own* sonar transmission, from the surface, from the sea bottom, from suspended matter and marine life throughout the volume of the sea, or from discrete scattering layers. This form of noise is known as " Reverberation " (see Fig. 5). Reverberation which is received (*via* a different propagation path) at the same time as a wanted echo is referred to as Common-range reverberation, *i.e.* having the same apparent range as the target.

Scattering Layers: Fish Buoyancy Control

The scattering layers appear to be due to fish kept in these layers either by their food supply, or possibly by their gas-filled buoyancy bladders. It is intriguing to speculate that if these fish rose too quickly or too far to release the surplus gas, the bladder would expand against the reduced ambient pressure, and so raise the fish further still, possibly causing the bladder to burst. Conversely, if the fish descended too far or fast, the bladder would be compressed, and the resultant loss of buoyancy might make the fish sink inexorably to the depths of the ocean.

Be this as it may, each buoyancy bladder, being elastically coupled through the waterlogged fish to the surrounding water, will absorb a proportion of all the acoustic energy passing within a half a wavelength of itself—*i.e.* over perhaps a thousand times its own cross section. For quite a wide frequency band this may be equivalent to complete interception of the energy over say ten times the cross section of the bladder, and at the actual resonant frequency the effective intercepting area may be increased up to hundredfold. Part of this energy will warm up the fish, but most will be uselessly re-radiated in all directions.

Let us imagine a ten-mile stretch of water, divided into parallel contiguous pipes (or say nylon stockings), each ten miles long and a few fish diameters across. Then (despite refraction) one tiny fish in each of these giant stockings might suffice to let little of the sonar energy penetrate as a coherent wave-front beyond ten miles. Thus, quite a low volume density of fish can produce an enormously high back-scatter and attenuation, and it can be surprisingly difficult to confirm such a fish distribution by non-sonar observation.

SONAR PROPAGATION MODES

Sound Layers in the Sea

The velocity of sound in water depends on its temperature, pressure, and salinity, increasing as these quantities increase. The normal pattern of variation of these parameters with depth leads to the ocean being divided for sonar purposes into three layers.

In the layer immediately below the surface, the mixing of the water due to convection keeps the temperature substantially constant with depth. The depth of this so-called "*iso-thermal*" layer can vary from a few tens of feet in the South China Seas to some hundreds of feet in the North Atlantic. In the iso-thermal layer, velocity increases slightly with depth since pressure is the only changing parameter (salinity being assumed constant).

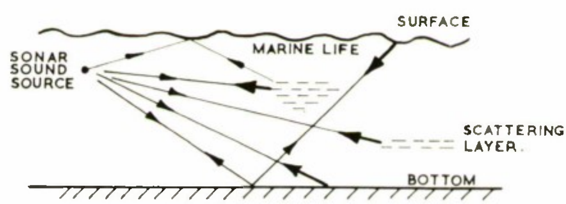

FIG. 5. Sources of reverberation.

Below this layer the temperature falls steadily with depth, until it reaches steady lower limit at a depth of several thousand feet. In this second layer, called *thermocline,* the decrease in velocity, due to the decrease in temperature, overrides the effect of increasing pressure in increasing velocity, so the velocity decreases with depth. (See Fig. 6).

Finally, where the temperature has reached to a constant value, the effect of pressure re-asserts itself and velocity again increases with depth. This is commonly referred to as the *Deep Layer.*

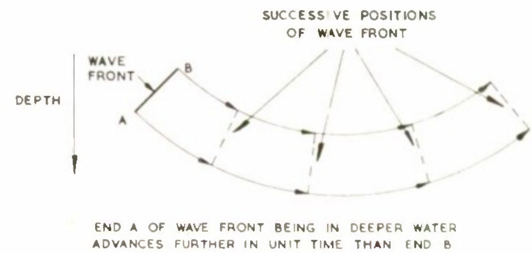

FIG. 7. Bending of sound path in velocity gradient.

The Surface Duct

The lower portion of the wave front of a beam of sound entering a layer where the velocity is *increasing with depth* (as in the isothermal layer) will advance more quickly than the upper portion. Hence the wave front will behave like a line of troops wheeling: thus sound rays launched at shallow angle downwards into the isothermal layer are bent progressively upwards (See Fig. 7), until they hit the surface. There they are reflected down again, and the process is repeated, as shown by the upper rays of Fig. 8.

Conversely, the steeper portion of a sound beam will have some downwards inclination left when it reaches the bottom of the isothermal layer. Hence it enters the thermocline *(where velocity is decreasing with depth)* and will be bent progressively further downwards.

Thus a sound beam, originally uniformly spread over a wide vertical angle, is split into two parts. The upper rays are bent progressively upwards until they hit the surface where they are reflected, mirror-like, to form further similar loops. Collectively, these rays " insonify " virtually the whole of the isothermal layer, which thus forms, from a sonar viewpoint, a " Surface Duct ".

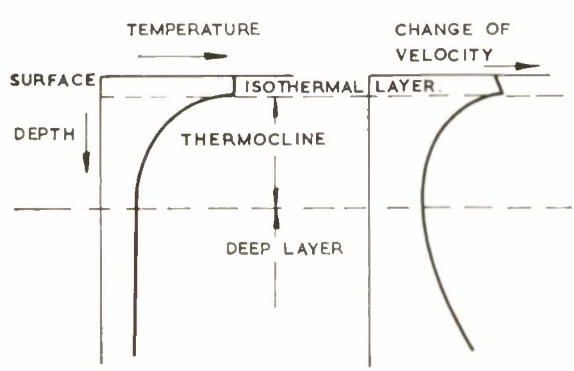

FIG. 6. Idealised temperature/depth and velocity/depth profiles.

As the surface roughness increases, until it becomes comparable to the acoustic wavelength, an increasing proportion of the sonar energy in the surface duct gets scattered omnidirectionally by the surface, and hence the desired *forward* reflection is accompanied by a large and increasing loss. A proportion of this scattered energy will of course return to the receiver as " reverberation ". The spread of the insonification of the surface duct, in vertical angle, produces a corresponding spread of loop-lengths between surface reflections, and so the reverberation is substantially continuous with range.

The Shadow Zone

The lower part of the sound beam bends fairly steeply downwards in the thermocline and thus its useful range is very severely limited. Between the two, there is a large volume which is not reached by the sound beam and therefore where a target can remain undetected; this is referred to as the *Shadow Zone* (see Fig. 8).

The existence of the thermocline is therefore seen to present a very real obstacle to the detection of targets below the isothermal layer—except at very short range. The obstacle is even greater in

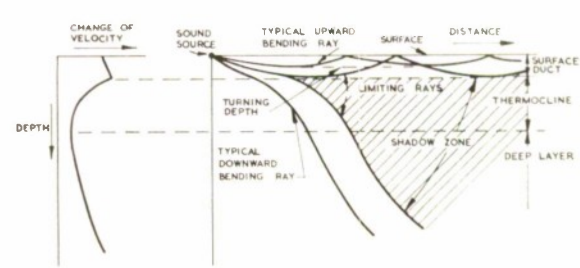

FIG. 8. Delineation of shadow zone.

the tropics, where the isothermal layer is often very shallow, and where the temperature gradient tends to be steeper than in temperate waters. We must therefore look for means of overcoming this obstacle.

Leakage Paths

Air bubbles and marine life in the volume of the "surface duct", and disturbances in its upper and lower bounds, scatter some of the acoustic energy into the "shadow zone" underneath. Similar effects are also produced by a more fundamental propagation mechanism:—

When we are looking for marginal effects, the "sound rays" should strictly have a width which is negligible compared with their radius of curvature, but is extremely large compared with the wave-length. Failing this, it is more accurate to think in terms of wide wave fronts launched at a discrete number of angles. Surface reflection and refraction (*i.e.* bending) at the "turning depth" of the equivalent ideal ray, transform these wave fronts into "modes" propagated along the duct; each such mode has an integral number of maxima and minima of sound pressure between the surface and its turning depth.

Fig. 9 shows one cycle, in space, of the first mode (or the bottom peak of a higher mode). The contours represent successive halvings of the acoustic pressure. The change in the pattern of these isobars, at the depth of maximum velocity, produces the effect of a highly attenuated wave front, centred on the depth where the sound velocity drops back to that at the turning depth. Thus this mechanism, too, produces leakage into the thermocline.

Unfortunately, "active" sonar echoes from "below-layer targets," due to any of these leakage mechanisms would normally be swamped by reverberation from assorted scatterers at the same range in the insonified regions outside the shadow zone.

The Sofar Duct

It has already been mentioned that there is a depth below the thermocline at which the velocity ceases to decrease and starts to increase again. If a sound source is placed at this transitional depth, a sound ray leaving it at a shallow angle above the horizontal will be bent downwards due to the increasing velocity in the layer above; similarly a ray below the horizontal will be bent upwards. Thus the sound will be confined within a region known as a *Sofar Duct*, and a source of suitable verticle angle will give continuous cover along this axis, *i.e.* at a depth of, say, 4,000 ft. Since

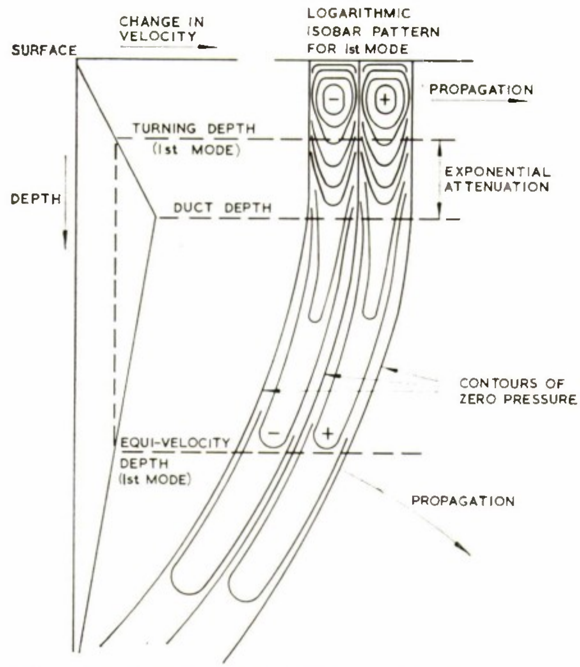

FIG. 9. A mode theory model of leakage from the isothermal duct.

the vertical velocity gradient is steeper above than below the axis of the duct, the crests of the "Sofar" ray paths are narrow and steep and the troughs wide and shallow (see Fig. 10).

Convergence Zone

Any up-going rays crossing the sofar axis more steeply will not have fully turned over before the bottom of the isothermal layer. Hence, they will escape from the sofar duct and will be bent upwards again to reach the surface. By the symmetry of up-and-down paths, such a ray can have originated as a down-going ray at the surface, if there is sufficient depth of water below the sofar axis to allow the increasing pressure in the deep layer to turn it upwards again.

Thus, the steep rays from a surface source, like the one illustrated in Fig. 11, can eventually return to the surface, where they will insonify a narrow annulus, at a range of some tens of miles, which is known as the *Convergence Zone*. After reflection at the surface, the ray can continue with repetitions of its preceding path, giving rise to a succession of such annular zones.

Reliable Acoustic Path

Alternatively we might endeavour to place a very deep sonar at the depth where the sound velocity is again equal to that at the transition

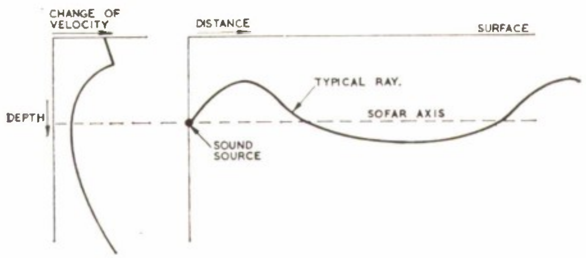

FIG. 10. Delineation of Sofar duct.

FIG. 11. Typical convergence zone ray in deep water.

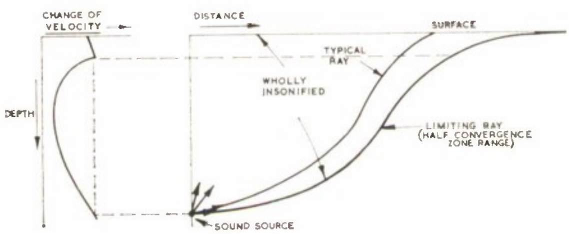

FIG. 12. Delineation of Reliable acoustic path.

between the thermocline and the isothermal layer. The changes of angle, by upwards bending, below the sofar axis, and downwards bending above, are then equal. Sound rays emitted horizontally or upwards from such a source could therefore penetrate into the isothermal layer with the same range of vertical angles as is covered by the source itself.

With a launch angle of zero degrees to the horizontal, this is equivalent to the trough of a convergence-zone ray path. Hence this mechanism —known as the " Reliable Acoustic Path "—can give gapless cover out to at least half the range of the first convergence zone (see Fig. 12).

Water-depth permitting, any downwards-going rays would be bent upwards until they re-cross the so-called " critical depth " at the same angle upwards. They would then continue in the manner already described, thus further extending the possible range.

Unfortunately, the critical depth of water required for these propagation modes generally varies from about 5,000 ft. in temperate waters to around 15,000 ft. in the Tropics, and a deep sonar does not give any really spectacular benefit until we approach these depths.

The *Convergence Zone* and *Reliable Acoustic Path* also pose fairly severe problems of common-range reverberation, which can probably be solved only by the use of sophisticated modulation techniques and large transducer arrays with high angular discrimination.

Bottom Bounce

It is clearly no easy problem to place a sonar at the great depth required for the Reliable Acoustic Path. There is however, another approach possible to cover the shadow zone due to the thermocline. This is to launch sonar rays fairly steeply downwards so that, after *reflection* from the sea-bottom, they enter the thermocline from below to give surveillance cover, possibly out to the range where bottom reflection, at progressively shallower angles, gives way to refraction, *i.e.* the first convergence zone. This " bottom-bounce " technique (Fig. 13) is limited by the fact that each of the two bottom reflections (go and return) is normally accompanied by serious attenuation, due to bottom absorption and omnidirectional scattering. This raises severe problems in making bottom-reflected echoes stand out over common-range reverberation, produced by direct back-scatter from the bottom or surface.

Energy Conversion

If our aim were energy-conversion rather than range and sensitivity, sonar would be in hot competition with radar or satellite communications for the booby prize as " the most inefficient man-made machine." The ratio of the echo power accepted in the receiver to the original radiated power may be equivalent to a " conversion efficiency " of one in one thousand million million million (*i.e.* the ratio of a 4-in. cube to the combined volume of all the Earth's oceans). Although the bottom reflection loss is small compared with this, the go-and-return loss of, say, a further 1,000 to 1 could still be a good bale of straw to break our camel's back. Thus the high reverberation and attenuation of bottom-bounce would present a severe challenge to the sonar engineer, who—in turn—would no doubt have to pose unorthodox and difficult hull-shape and power-supply requirements to the ship designer.

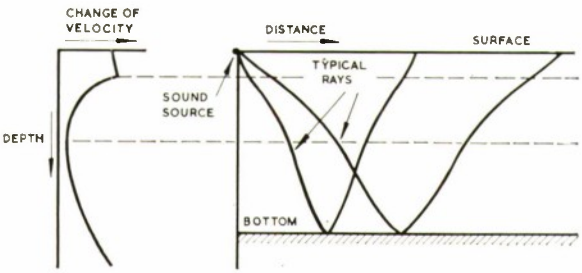

FIG. 13. Bottom bounce.

Multi-paths

At the longer ranges, we can rarely observe the simple, single, idealized propagation modes described so far. Instead, constituent echoes are produced over a number of combinations of go and return paths, involving different degrees of ray bending, and perhaps different numbers of surface and bottom reflections. This may produce a somewhat "smeared" single echo or a number of discrete echoes from a single target. (The simple example of Fig. 14 includes 25 combinations of go and return paths and 15 discrete path lengths).

This situation is further complicated by frequency-dependent surface, bottom and volume (biological) attenuation, distortion and scattering, by the rapid fluctuations of some of these phenomena, and by the variation of some of these effects with direction, depth, place, time of day, season, weather, signal amplitude, *etc.*

Variable Conditions

Similarly, the picture of an isothermal duct, a simple thermocline, and colder isothermal deep water is a simplified generalization and idealization of difficult, complex and highly variable thermal structure. Some of these variations are produced by "internal waves" (*e.g.* at the interface between two layers of water), which may be the result of deep convection currents, flowing over ridges and canyons in the sea bed. These and other currents are caused by energy exchanges of the sea: with the atmosphere, the sun, the moon, geophysical heat sources, the earth's rotational momentum, and the earth's gravitational field.

There is tremendous scope for further research to identify, measure and interpret the relevant factors, so that we can compute and predict our sonar performance.

OTHER SONAR DEVICES

General

All the propagation and noise problems are in principle common to surface-ship or submarine hull-mounted equipments, towed "variable-depth" sonars, helicopter dipping sonars, or air-dropped disposable sonobuoys, and the submarine-detection problem is so severe that we cannot ignore any of these techniques.

Explosive Sound Sources

In sonobuoys, or other devices which are expendable, or are operationally limited to a small number of "pings", it may not be worthwhile to convert chemical into acoustic energy *via* the intermediate stage of electricity. Hence direct conversion may be employed, using small charges for "Explosive Echo Ranging." However, these simple "bangs" do not permit of Doppler velocity discrimination or some other sophisticated forms of signal processing.

DATA EXTRACTION PROCESSING AND DISPLAY

Variety of Tasks and Data

A sonar operator has three main functions:—

- Detection (is there an echo amidst the noise and reverberation ?)
- Classification (is the echo a submarine, countermeasure, fish ?)
- Tracking (what is its position, course, and speed ?).

For these tasks, he should study the character (*i.e.* mean position, spread and distribution) and the history of each of the five parameters of the echo, *e.g.*

Parameter	*Character*	*History*
Range	Echo length	Change in position and character with time
Bearing	Target extent	
Elevation	Echo depth and vertical extent	
Amplitude	Echo strength	
Frequency	Closing component of speed (Doppler)	

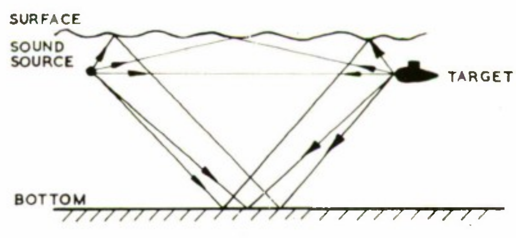

FIG. 14. Example of multi-path echoes.

Difficulty of Raw Display

The appreciation of track history is complicated by the one-minute interval between " pings ", in a sonar catering for a maximum range or, say, 25 miles. The interval is ill matched to the chemical persistence of vision in the human eye, or to remembrance, by the human brain, of the fine detail of a pictorial pattern.

Even apart from this difficulty, we clearly have too many co-ordinates of information for a two-dimensional display, and we have too much "raw" information for the sonar operators.

Need for Other Sensors

This situation is aggravated by the intermittent nature of most sonar contacts, and the difficulty of classification. These problems call ideally for the combination of the data from several sonars, from own ship and ships in company, together with passive intercept and analysis of the contact's radiated noise and possibly its sonar emissions. Finally, we may want to use the radar picture of surface targets, to distinguish between sonar echoes from surface ships and those from submarines.

Tasks for Automatics

Thus, clearly, there is scope for producing automatic devices to help process the incoming data. Here we can distinguish three main requirements:—

(a) The rejection of signals which are clearly inconsistent with submarine echoes;
(b) the direct acceptance of signals which can be immediately classified as submarines—possibly by association with already established submarine tracks; and
(c) processing, combination and presentation of the remaining signals, in a form which helps the operator in supplementing or guiding the operation of the sonar data computer.

Tactical Data Handling

Following data extraction, by a combination of man and machine, we would have the separate problem of handling the resultant tactical data, *i.e.* plot compilation, evaluation, tactical decision and weapon control. This—again—is a task which should be shared by man and machine in complementary rôles.

IDENTIFICATION AND COMMUNICATIONS

IFF

Once we have established and classified a sonar contact, we still must identify it, as friend or foe. This requires secure and reliable challenge and response techniques immune to the vagaries of the propagating medium, and to Doppler distortions.

Communications

When submarines are co-operating with each other—or with surface ships—identification should normally be followed by communication. Underwater communications, like sonar, are complicated by the slow acoustic propagation speeds and narrow band widths available, and by Doppler and multipath distortions. These problems are far more severe than their counterparts in, say, H.F. radio communication *via* the ionosphere.

TORPEDOES AND OTHER WEAPONS

Torpedoes—General

Having developed our sonar, overcome the problems of propagation, noise and reverberation, detection, classification, identification and decision, we eventually want to fire a weapon. Most probably this will be a torpedo, and this means, nowadays, an underwater guided weapon of extreme sophistication.

Admittedly—unlike airborne guided weapons—a torpedo can often be made neutrally buoyant, so that one can recover many development test vehicles. On the other hand there are special problems in observing the behaviour of torpedoes, running deep against artificial moving targets.

Air-dropped Torpedoes

Furthermore, an air-launched torpedo, and its built-in sensitive control system, has to withstand the aircraft, helicopter or rocket environment, the water-entry shock, and the deep-water pressure of, say, 100 tons per square foot. Once in the water, it has to behave " intelligently ", without any further help from the launching vehicle. It must be hydrodynamically stable, highly manoeuvrable, as free as possible of flow-induced and propeller noises, and fast enough to overtake a nuclear submarine.

The propulsion engine of such an underwater guided weapon must have a very high power/weight ratio, and must make efficient and safe use of high-energy fuels. In addition, it should be silent, have no gaseous wake, and cause no serious corrosion. It clearly has no access to atmospheric air as an oxidant, and it has to operate with equal efficiency against back pressure of from one to, say, a hundred atmospheres.

Submarine-launched Torpedoes

Similarly, a submarine's torpedo-launching system must maintain its performance over a very wide range of pressures. The submarine torpedo

itself may have to survive exposure to high pressures and corrosive salt water for prolonged periods.

The non-linear ray paths of sonar signals, and their slow speed of propagation, compared with the time-constants of weapon control, limit the quality of the guidance available from the launching submarine.

Wire Guidance

This situation would be improved by using a wire link to transmit certain signals from the torpedo back to the submarine, and to send mid-course guidance instructions from the submarine to the torpedo. Since it would not be possible to drag the wire through the water, both the torpedo and the submarine must then carry sufficient wire, and pay it out according to their respective movements after firing, so that the wire can remain stationary in the water.

This can be achieved by means of an " inboard " wire dispenser within the torpedo, together with an " outboard " dispenser ejected initially with the torpedo, but then held close to the submarine by a short armoured cable (see Fig. 15).

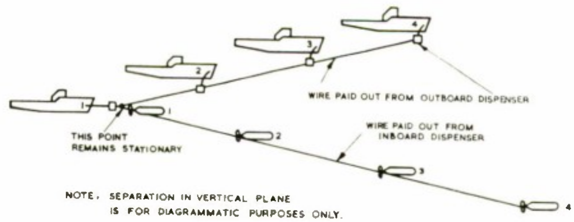

FIG. 15. Diagram illustrating successive positions of submarine and torpedo as wire is paid out from both.

Final Homing

Even so, mid-course guidance information for torpedoes can never be as precise or up-to-date as for airborne weapons. In addition, target classification and discrimination against reverberation are much more difficult than in normal anti-aircraft missiles, and torpedo decoys are well established as a countermeasure. In order to deal with these various problems, our underwater guided weapons need a very sophisticated " brain " for homing and fuzing, and if necessary for a renewed search and re-attack. Indeed, the provision of this tactical " logic " makes a modern torpedo considerably more complex, electronically, than a contemporary anti-aircraft guided weapon.

Warheads and Fuzes

Surface warships with their many watertight compartments and their countermeasures equipment, or submarines capable of withstanding the pressures of extreme depth, set difficult problems in the design of torpedo warheads and fuzes.

Considerable sophistication can be involved in studying the mechanisms of explosive damage to ship and submarine structures, and in optimizing weapon warheads accordingly.

Since the weapon may achieve only a glancing impact, or—as in mines—may even be intended to explode at some distance from its target, proximity fuzes must be provided. These may use magnetic, electro-magnetic, acoustic or optical techniques to determine the desired instant of detonation, and to achieve immunity from the disturbing effects of the sea-surface or bottom and from deliberate or accidental interference by the victim's equipment.

Air Transit

The intermittent nature of sonar contacts makes it desirable to follow-up an apparent detection rapidly, with the delivery of a homing weapon at the so-called " datum ". It would of course be even better if, on arrival at this datum, the delivery vehicle could perform an acoustic or magnetic search, to re-locate and classify the target, and could return the weapon unused, if this endeavour were unsuccessful. Rocket, drone aircraft or helicopter torpedo-delivery systems, benefiting from the speed of air flight and from radio guidance, can meet some or all of these requirements, as illustrated in Fig. 16.

Mortars and Rockets

For close range attack on slow-moving or bottomed submarines, there is still a need for mortars or rocket systems with proximity-fuzed projectiles. These systems must be designed to cope with any interference with sonar observation of their target, caused by their own explosion bubbles.

MINE WARFARE

Influence Mines and their Sweeping

Moored contact mines can be troublesome in narrow shipping channels, but their range is very limited, and they are relatively easily located and cut loose by wire sweeps.

Hence the main mining threat is that due to influence mines, normally resting on the seabottom in shallow waters, and actuated by the magnetic, acoustic or pressure field of a ship, or by a combination of two or even all three of these effects. These mines can be swept by a vessel which is sufficiently small, silent and non-magnetic not

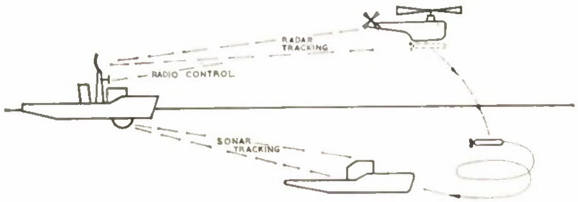

FIG. 16. Schematic arrangement for air-delivery of torpedo.

to actuate the mines, but which can tow devices giving a realistic simulation of a normal ship's influence field.

This sweep field should be as extensive as possible, but not so large as to explode mines dangerously close to the sweeper. Particularly with an acoustic sweep, where the acoustic field contours vary with the sound frequency, depth of water and nature of sea bottom, it is difficult to control conditions so as to combine an assured effective sweep width, acceptable for operational planning purposes, with maximum safety of the sweeping vessel. In addition, the sweep device must either be expendable or robust enough to survive the mine explosions—which it is designed to set off.

Arming Delays and Ship-Counts

A common countermeasure to sweeping is the pre-settable arming delay. This is a clock which controls the period or periods during which the mine is 'live', *i.e.* responsive alike to real ships and sweeps. Sweeping a minefield laid with mines fitted with such a device can lead to a false sense of security, since lack of explosions can merely mean that the field is only temporarily dead and may well become alive later.

Another countermeasure is the "ship-counter", capable of being pre-set to an arbitrarily chosen number, between one and perhaps a score; only after it has been actuated that number of times does the mine in fact blow up. Thus we can rarely be sure that we can provide sufficient sweep-passages to blow up all mines, but neither can we be sure that all the ship-counters will be set high enough to allow even one or two of our ships to pass through safely prior to sweeping.

Minehunting

One answer to this is to *hunt* mines, by surveying the sea bottom with sensitive sonar or magnetic search systems, rather than sweeping. When a mine has been found, we can then destroy it by explosive counter-mining. Minehunting can however be very difficult where there are a large number of uncharted mine-like objects—or rocks—or where the bottom and tidal conditions cause mines to be buried in rocky clefts, sand or mud. Hence it may be desirable to choose shipping channels suitable for minehunting. This may involve oceanographic research, to predict the probabilities of mine burial. However, channels suitable for minehunting are not always available in our own areas, and even less so in enemy waters.

Assault Mine Warfare

Hence mine-*sweeping* might be required in, say, an amphibious assault operation. In general, the sweeper force is limited, and so is the time allowable for mine-sweeping. If the enemy exploited this by the use of high ship counts, we could push all our key ships through, before this count is reached; conversely, if he uses low counts, even our limited sweeper effort can quickly clear a narrow channel.

It is then best for the enemy to use a random spatial distribution of mines and a random distribution of ship counts. Our best response to this is a random distribution of sweeping effort. This gives a statistically much reduced—and calculable—risk to our ships. However an area which is suitable for mine*hunting* would still be much better for our peace of mind.

Navigation and Control for MCM

To clear defined areas or channels, without gaps—and with minimum overlaps between swept tracks—requires extremely precise navigation. Furthermore, in minehunting we must be able to pinpoint the position of a suspected mine, in order to investigate it from a more favourable aspect angle, or at a more opportune time.

Indeed, navigation for minesweeping or hunting has to be more accurate than for almost any other activity, and requires specialized techniques and equipment. Similarly, delicate ship-handling for mine countermeasures, at low speeds, in the face of winds and currents, and with minimum engine and propeller noise, requires special ship-control facilities.

Effects of Swell

Sea swell can entail pressure fluctuations similar to those produced by the passage of ships, and so can affect the design and operation of both mines and minesweepers.

Swell also causes the movement of conducting sea-water in the earth's magnetic field. Now sea-water, like any other conductor, tries to keep its associated magnetic flux constant and, if necessary, generates an "eddy current" to preserve its magnetic "*status quo*". In the process, however, it

changes the field elsewhere in its vicinity. These changes, though small, can be significant in our context.

Similarly the roll and pitch of a minesweeper in a rough sea, or its forward speed, could produce eddy-currents in metallic parts of the sweeper or in the adjacent sea-water, which are magnetically significant. Hence, in addition to all the basic precautions to make the ship and its components and equipments magnetically neutral, it would (ideally) be desirable to exercise continuous control over the current in an array of "degaussing" coils, so as to neutralize the varying residual magnetic fields due to the minesweeper.

Mine Investigation

The design and use of mine countermeasures equipment, and indeed our general tactics in the face of mining, depend on our knowledge of the nature of the mines. Hence there is an important requirement for the recovery and examination of novel enemy mines, and this poses severe problems, in rendering these safe and retrieving them from the ocean floor, whilst keeping their actuating mechanism substantially intact, for analysis.

MAGNETIC ANOMALY DETECTION

General

Airborne Magnetic Anomaly Detectors known as MAD or "mad" can be used to look for submerged submarines, or at any rate try to re-locate and classify them, where their presence in the vicinity is already suspected. MAD may employ "flux-gate" magnetometers, in which two similar pieces of magnetic material are biased, in opposite directions, to the brink of magnetic saturation; we may then observe the *difference* of their magnetic responses, as the ambient field drives one piece right into saturation and the other away from it.

Nuclear Resonance Magnetometers and their Problems

There are now also resonance magnetometers, which note the cyclic effect of the magnetic field on the orbit of protons or electrons, in certain atoms. These instruments can be much more sensitive still, but they measure the *total* magnetic field, *without regard to direction*: hence, if the proximity of a submarine were to alter the *direction* of the earth's field without much effect on its total *magnitude* these sophisticated devices might have little extra to offer us.

Furthermore, the wanted signal may be masked by magnetic fluctuations, due to the ionosphere, or sea swell, or irregular movements of the carrying vehicle. Other disturbing magnetic fluctuations are caused by electric or magnetic devices in the vehicle, *local* variations in the earth's field, due to magnetic rock at the sea bottom, or *temporal* fluctuations in the magnetic field, due to variable convection currents in the earth's ionized liquid core. These, and other forms of "magnetic noise", seem to be designed by nature to drive the poor MAD operator indeed mad.

DESIGN OPTIMIZATION

A modern anti-submarine weapon system poses an extraordinarily complex and challenging problem of design optimization. The number of desiderata and constraints is very large, and virtually every design choice interacts critically with many others. At one level one has to weigh up the interaction between:—

(i) ship or aircraft,
(ii) the detection and classification system,
(iii) above water weapon delivery system (if used), and
(iv) the terminal weapon.

Assuming a torpedo terminal weapon is involved, we then have to consider (*inter alia*) the following parameters or sub systems:—

(a) fire control
homing
guidance
fuzing
warhead

(b) range
speed
propulsor
motor/engine
energy-source

(c) hull size
shape
profile drag
skin drag
drag-reducing devices
selfnoise
radiated noise

(d) stability
control
orientation-reference
position-reference
depth sensor

(e) homer beam forming
modulation
signal-processing
tactical logic
operating modes
computation techniques

(f) materials
crushing-strength
shock-resistance
corrosion-resistance
weight
buoyancy
trim

(g) carrying system
launching system
handling
stowage
loading

(h) magazine-safety
logistic support
test facilities
maintenance
training

These and other factors have to be assessed in relation to their interactions, and with regard to

(i) technical problems to be solved,
(ii) facilities and resources required,
(iii) impact on trials requirements,
(iv) effect on eventual production—and cost,
(v) adaptability to various ship and aircraft configurations.
(vi) procurement target dates and resources.

Sonar, mine countermeasures and other aspects of undersea warfare research and development encompass a similarly wide range of basic science and advanced technology; environmental and operational knowledge; economic and administrative considerations. Indeed, most modern applied science makes similar demands on broad-based well-informed judgement. However, in undersea warfare much of this depends upon oceanographic, technological and tactical know-how, backed by specialized shore-based test facilities, underwater tracking, calibration or measuring ranges, and floating laboratories and trials vessels; this expert background is, in the main, unique to the Royal Naval Scientific Service (and its counterparts in the other principal maritime nations).

CONCLUSION

Light does not penetrate far into the depths of the ocean, and underwater sound is no better at piercing the sea/air interface. Similarly, the engineers and scientists, whose products work beneath the seas, have little contact with their professional colleagues under the open sky. This article has been written with the aim of making a small hole in this barrier, and revealing something of the challenging and fascinating scientific problems in undersea warfare.

The 7th International Conference on Medical and Biological Engineering, Stockholm 1967

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Organization

Medical and biological engineering is an interdisciplinary field, in which one may meet a spectrum of workers ranging from boiler-makers to psychologists. Organizing a conference to interest and inform such a variety of people must have been a hard task, apart from the obvious difficulties of presenting about 450 papers in five days and a half. The success of the conference was a great tribute to the organizing committee. The programme was organized in six general sessions and 40 specialist sessions, with up to six sessions going on at one time. Space was also found for informal discussions and scientific films. Papers were allowed either 15 or 30 minutes for presentation and discussion, and all concurrent sessions were started together. With completely ruthless chairmanship it was therefore theoretically possible to listen to paper four in session three, then run to another part of the building to hear paper five in session four. This system worked remarkably well except with the chairmen from the U.S.A., who were almost invariably too polite to interrupt speakers in mid-sentence. The physical fitness induced by all this running partially compensated for the mental confusion brought on by the occasional need to be in three places at once. This report of the conference is intended merely to mention the highlights as seen from the author's personal viewpoint; a comprehensive digest of the papers presented is now in the library at R.N.P.L.

General Sessions

Five of these sessions were of review-type papers, on subjects such as Artificial Organs, International and Interdisciplinary Co-operation, Current Trends and Education in Biomedical Engineering. The sixth session ("Special Lectures") included some papers that would not readily fit into any given specialist session. Like many reviews, most of them

included little that was new to any one in their particular field, but were intended mainly for their disciplinary neighbours. The sessions probably largely achieved their objectives of acquainting the biologists with new techniques from the physical sciences and the physical scientists with current biological problems.

Specialist Sessions

It was difficult for a physiologist to evaluate some of the more mathematical papers even when the subject was obviously highly relevant to physiology. The paper (numbered 1-6 in the Digest) entitled "Numerical Hydrodynamic Calculations for Branching Pulsatile Flow in Flexible Tubes", by A. C. L. Barnard *et al.* was an excellent example of an apparently high-quality paper almost perfectly incomprehensible to those who might be expected to need to understand it. The principal justification of such events as this Conference must be the opportunities afforded the life and physical scientists to discuss such things over coffee rather than dismiss the possibility of understanding.

On the first day, the sessions on Telemetry and on Computer Analysis of Electrocardiograms were concurrent, so a good deal of exercise was obtained. R. S. Mackay's "Telemetering Studies from Aquatic Animals" gave some fascinating glimpses of expertise, and it is to be hoped that the Royal College of Surgeons will succeed in sponsoring a visit by Dr. Mackay to give a three-day course on Bio-Medical Telemetry in 1968. In the computer analysis session it appeared that one of the most valuable systems had been developed at the new university of Umea in northern Sweden (paper 4-8).

On the second day, the session on "Foetal Electrocardiography and Phonocardiography" showed that R.N.P.L. is not alone in trying to take measurements from subjects within sealed chambers. In the neurophysiology session a fascinating paper (12-14) on the effects of pulsed electrostatic fields on the central nervous system gave rise to some rather disturbing thoughts on induced drowziness in personnel manning some of our more electronic defence installations.

The third day was memorable for a paper (13-10) by Van Citters *et al.* giving some blood pressure and flow data telemetered from giraffes in the natural environment. The simple acts of raising and lowering the head produced blood pressure changes that would result in fainting and then death in humans. Dr. Franklin, who designed the instruments for this investigation, has promised assistance to R.N.P.L. in making a similar instrument for divers. His grumbles about interference by bubbles suggest that a valuable bonus of the projected blood-flow measurements at R.N.P.L. will be a means of detecting any bubbles formed in the blood during decompression sickness. Also on this day a paper (21-1) in the ultrasonics session, entitled "Three-Dimensional Imaging by Ultrasound Holography" would have interested anybody working in Sonar.

On the fourth day, the afternoon session on "Aids for the Handicapped" provided some remarkable examples of the application of physical sciences to biological problems, mainly in the areas of blindness and absence of functional limbs. This was followed by the General Assembly of the International Federation for Medical and Biological Engineering, and in the evening a banquet was held in Stockholm's City Hall, the building in which the Nobel Prize presentations are made.

On the fifth day, some useful practical hints were obtained from the sessions on "Techniques in Electrocardiography" and "Instruments". The most memorable of the scientific films showed a "Moon-Walker" adapted to carry a limbless child; for the first time in her life, she could climb stairs, cross the road and walk on a beach.

The sixth day's sessions, on "Models and Simulation" (analogues, unfortunately!), "Instruments" and "Artificial Kidneys and Lungs" contained a number of interesting papers. The paper (40-5) by Wiseman *et al.*, "A New Silastic Membrane Oxygenator Life-Support System" reported some interesting progress with these systems, and suggested to the writer that such devices might yet be used to provide divers with oxygen from the sea.

The 8th International Conference on Medical and Biological Engineering will take place in Chicago, from 20th to 25th July, 1969.

Other visits had to be made in the writer's own time, but it was found possible to visit the Naval Diving Training Centre in Stockholm and the Department of Naval Medicine at the Karolinska Institute. It was interesting to note how the instrumentations system at the latter paralleled one now under consideration at R.N.P.L. Less official tours were made of the Stockholm Archipelago, and of the museum housing the WASA—the 300 years old Swedish flagship recovered from the bottom of Stockholm harbour in 1961. The fact that all guns were found to be in their correct positions contradicted the court-martial findings of the time, and the probable cause of the capsizing was a defaulting contractor who supplied only 120 of the 400 tons of ballast required.

FLATNESS CONTROL IN OPTICAL POLISHING

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ABSTRACT

A polishing technique is described which was developed during the course of a research programme on gallium arsenide lasers. The method of flatness control used by Payne Products, has been adapted to maintain the flatness of the polishing plate. Machine polished surfaces up to 4 in. diameter have been produced with flatness errors of less than $\lambda/2$, and small laser surfaces are polished with flatness errors including edge radii of less than $\lambda/20$. (λ=5900 Å).*

Spherical surfaces with large radii of curvature have also been polished using this method of control.

Introduction

Semiconductor device technology is to a large extent dependent on critically prepared surfaces, and in particular gallium arsenide lasers require the production of surfaces which have flatness errors including edge rounding of less than $\lambda/20$.

Optical polishing traditionally relies on skilled personnel. The components are mounted on to a block, which is then moved over a polishing plate in such a manner that the surface of the polisher remains reasonably flat.

In this instance, the small quantities, minute size of the parts, and lack of skilled personnel, precluded the employment of the usual methods of optical polishing.

These problems have been solved by using special fixtures, and adapting the method of flatness control employed in " Lapmaster " machines, where the lapping plate is continuously controlled by three or more conditioning rings.

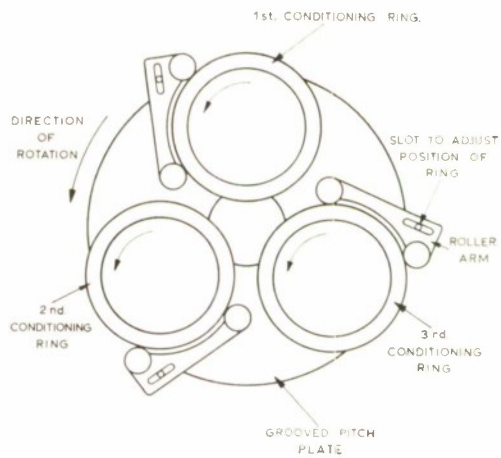

FIG. 1.

Description

Because success in this field often depends upon a detailed knowledge of the process, the techniques developed are fully described.

A polishing machine with a 12 in. diameter pitch plate is used (Fig. 1), and this is conditioned by three stainless steel rings which are faced with annular discs of *Pyrex* to prevent the formation of iron oxide. These are located by adjustable roller arms as shown in Fig. 1.

The contour of the pitch plate is changed from a concave to a convex surface by moving the rings inwards or outwards, and in between these conditions exists a position of the rings where the flatness of the pitch plate is maintained. Flatness measurements can be made by polishing a test piece, which is checked with an optical flat to determine the direction, and approximate amount, to move the rings. This procedure is repeated until flatness of the polisher is achieved, and further adjustment is rarely required.

Swedish pitch of $\frac{1}{2}$ mm. hardness is generally used, which is measured with a standard 14° probe. A suitable mixture for this type of polishing consists of 4 lb. pitch, 10 oz. 100 mesh wood flour, 2 oz. beeswax and 2 oz. resin, which are thoroughly stirred at 120°C before pouring on to plates which are pre-warmed to 80°C.

The polishing machine has been equipped with a turning attachment to enable the pitch plate to be machined quickly and accurately *in situ*. A groove is cut in the pitch with a 90° Vee pointed tool (Fig. 2). This produces a form similar to a gramophone record, but with a groove width of approximately 0·03 in. The groove performs several functions which are as follows:—

(a) After re-cutting, the crest of the groove is rapidly brought to the flat condition by the rings.

*Payne Products International Ltd. (" Lapmaster "), Buckingham Avenue, Trading Estate, Slough, Bucks.

(b) The temperature effects encountered in optical polishing[1], are minimized by the groove which assists in distributing cooling water.

(c) The groove provides accommodation for stock removed and spent abrasive.

Sufficient abrasive to complete the polishing operation is placed in the first conditioning ring (Fig. 1), and a supply of filtered deionized water is arranged to drip into the same ring. The second ring spreads the mixture and assists in breaking down the abrasive into finer particles. The second and third rings are used for work location, but when minimum edge rounding is required, only the third ring is employed.

The mirror faces of gallium arsenide lasers which are typically 0·5 in. × 0·05 in. at this stage, are polished parallel and at right-angles to a previously polished face. This is achieved by clamping the laser ' bar ' in a fixture so that the original face is located by an accurate right-angle block. Two beam fringes on the mirror face of a laser are shown in Fig. 3, and this has been polished with 0·3μ alumina on a pitch plate. The slight rounding on the left-hand edge (Fig. 3) is unimportant as this edge is not incorporated in the finished device. The protection provided by the right-angle location block, has prevented rounding occurring on the opposite edge.

It is usual to remove 0·005 in. to 0·001 in. in the polishing cycle. This takes from 1½ to 8 hours, depending on the surface area, material, polishing speed and pressure applied, which vary from 50 to 75 r.p.m. and 2 to 100 p.s.i. respectively.

Materials successfully polished with 0·3μ alumina include: stainless steels, molybdenum, copper, glass, quartz, germanium, gallium arsenide and indium antimonide.

Spherical Surfaces

This technique is suitable for polishing surfaces which have a large radius of curvature. Although four metres is the smallest radius that has been polished, a radius of three times the diameter of the polishing plate should not present any difficulty. The smallest practical radius would be one approximately the diameter of the polisher, but would require a modification to the roller arrangement.

It is necessary to machine the required curvature on the lapping plate, lapping rings, polishing plate and work piece. This is accomplished by radius generation[2], in a vertical milling machine with inclined head, rotary table, and single point cutting tool.

FIG. 2. Cutting groove in pitch plate.

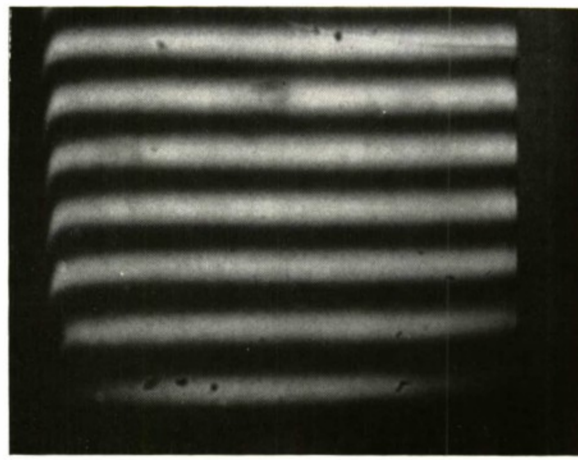

FIG. 3. Typical interference pattern on laser mirror.

Conclusion

A variety of semiconductor and other materials have been polished by relatively inexperienced personnel, and in every case the quality of surface finish, flatness, and minimum edge rounding, has been achieved to within the accuracies stated.

Also, several long focal length mirrors, both convex and concave, have been polished by this technique.

Acknowledgements

The author would like to express his appreciation of the valuable assistance received from Mr. G. R. G. Keys during the course of this work.

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A NEW GETTER SYSTEM FOR OPAQUE VACUUM TUBES, USING SAMARIUM OR THULIUM

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SUMMARY

A new getter system for opaque or metal-walled tubes is described, in which thulium or samarium is fired off the tube envelope by external heating. This eliminates the need for insulated electrical lead-through seals. Also, because the envelope temperature can be checked externally, some visual control of firing is provided, resulting in greater reliability than is obtained with "blind-fired" conventional barium getters.

The rare earth metals can be used as general tube getters and their ability to absorb a succession of different gases has been demonstrated. The importance of sorption measurements with a succession or mixture of gases is stressed and quantitative data are presented.

Introduction

In opaque or metal-walled vacuum tubes, conventional barium getters can only be fired by the direct passage of an electric current. This necessitates having an insulated electrical lead through the tube envelope, which not only complicates the structure of the tube, but is a potential source of leaks.

Moreover, variations in the mechanical dimensions and electrical properties of getter assemblies (such as sheath wall thickness, contact and weld resistances) can lead to differences in the degree of firing achieved by a single power-time schedule. A schedule which heats the majority of getters correctly may nevertheless burn out or under fire a significant minority.

A new system of gettering vacuum tubes is described in the next section. This requires no insulated electrical lead-through seal, and it provides a measure of visual control of firing. In addition, unlike "flashless" getters of the sintered coating type it requires no hot-running components for its gettering action.

Envelope Getter Firing System

Principle of system. In this new system of getter firing, before assembly of the tube, a suitable getter material is evaporated on to one surface of a component which ultimately forms part of the tube envelope. This component will be referred to as the tube "lid." After the tube has been assembled, evacuated and processed, the getter film is vaporised by rapid external local heating of the lid of the envelope and is condensed onto a suitable surface nearby inside the tube. This can be done either before or after sealing off the tube from its pumping system.

As the heated portion of the envelope glows red for a short time, its temperature may be estimated either by optical pyrometry or by another technique described later. Thus although the evaporated film itself cannot be observed, nevertheless it is possible to verify that the getter evaporating structure or lid has reached the correct temperature. Moreover, no insulated electrical leads through the tube envelope are required.

Choice of Getter Material. Samarium and thulium have been used successfully as getters fired off the envelopes of vacuum tubes. These rare earth metals were selected after an initial investigation indicated that they had most of the properties essential to such a firing system.

The getter film must not suffer excessive atmospheric oxidation during the time interval between its evaporation onto the tube lid and the sealing of this lid as part of the tube envelope. The conventional getter, barium, is ruled out on this account. Exposure to the atmosphere results in excessively rapid oxidation right through the barium film. Preliminary experiments showed that samarium and thulium have adequate stability to atmospheric pressure. Atmospheric oxidation penetrates to a limited depth, after which the metal is left for subsequent re-evaporation in the tube.

In common with the other rare earth metals, samarium and thulium were expected to be highly reactive with gases commonly found as residuals in vacuum tubes. Preliminary experiments verified that this assumption was correct. It would appear therefore that the rare earth metals represent a large field of suitable general getter materials, hitherto neglected, which may well reward further investigation.

The getter material must be sufficiently volatile for it to be evaporated during a feasible envelope heating cycle, for example two seconds at 1,000°C. This would require the vapour pressure of the getter at that temperature to be within the range

0·1 to 1 torr. Honig[1] gives the values 1·5 and 0·2 torr at 1,000°C for samarium and thulium respectively, both of which therefore appear to be satisfactory.

However, there is also an upper limit to the volatility of the getter, in that it must not be evaporated appreciably during tube bakeout. Honig[1] gives the vapour pressures of samarium and thulium as 6×10^{-7} and 7×10^{-9} torr respectively at 450°C (a typical tube bakeout temperature). These values indicate that thulium evaporates at a negligible rate during a 450°C bake-out, while samarium, which evaporates more rapidly, may be acceptable for many applications, particularly if a lower bake temperature is allowable.

For example, it can be shown from simple kinetic theory that a thulium getter film in a tube with a half litre/second conductance pumping stem, will evaporate a monolayer of thulium in about 10 hours during a 450°C bake-out. Samarium would lose a monolayer in six minutes at the same temperature, or in one hour at 400°C or in 10 hours at 360°C. In no case would condensation take place on the tube walls.

Getter Firing Technique Details. The tubes used for testing the properties of samarium and thulium films fired off the envelope are illustrated in Fig. 1.

A samarium or thulium film of area 1·8 cm² and weight 15 to 20 mg was vacuum evaporated on to a chemically etched, vacuum furnaced molybdenum " lid " of thickness 0·038 cm. Molybdenum was chosen because it was known to alloy insignificantly with samarium or thulium. Other metals may be satisfactory, but they have not yet been tried.

The " lid " was then brazed into the open end of the tube (also made of molybdenum) using an atmosphere of dried argon. The exterior surface and the brazing region of the lid were previously nickel plated to a depth of 0·001 to 0·0013 cm.

The metal components of the tube were vacuum furnaced before assembly for five hours at 900°C, and the completed tubes were pumped and baked at 450°C for two hours, after which they were sealed off. The getter was fired either before or after seal off. The relative merits of these two alternatives are discussed at the end of this section.

The getter was then fired off the lid by external heating pulses. A weighed chemically etched disc of molybdenum, placed about 0·5 cm from the tube lid, acted as a condenser for the vaporized getter. Rapid localised heating of the lid has been achieved either by electron bombardment in a vacuum or by striking a low current arc on to the lid using a commercial argon arc welder. The arc technique is the simpler and more versatile. Laser heating is another attractive possibility.

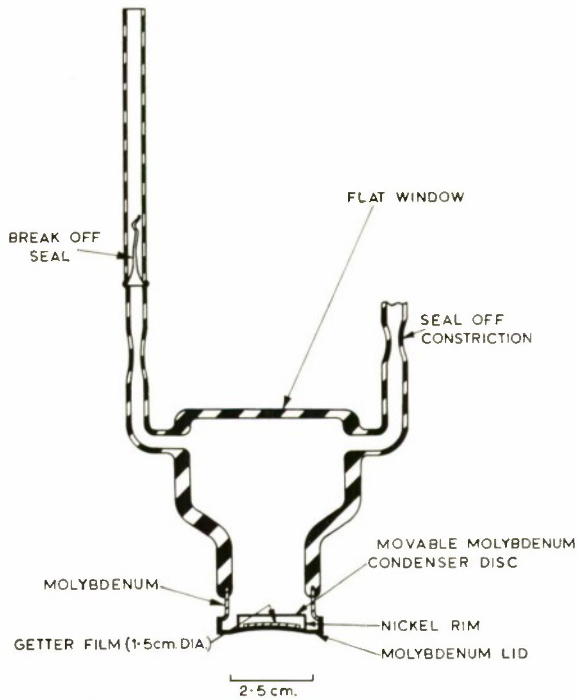

FIG. 1. Getter test tubes.

An adequate reproducible temperature-time schedule was obtained using a fixed setting on the welder (20A arc current). The tungsten electrode (negative with respect to the lid) was of 0·16 cm diameter. Its end profile, very roughly hemispherical, was found not to be all critical and setting of the electrode-to-lid distance, 0·080 cm, by feeler gauge was quite satisfactory. An argon flow rate of 5 litres per minute was used.

Samarium films were fired using 2·0 second arc pulses, giving instantaneous peak envelope temperature of 1300 - 1400°C, while for thulium 2·5 second pulses peaking at 1400 - 1500°C were used. Temperatures several hundred degrees lower than these can be used, but it was found that rapid firing was more conveniently achieved with higher maximum temperatures. The subject is discussed more fully in Appendix B. Each pulse completely vaporized the getter from a circle of about 3 mm diameter. No loose particles of getter films were found on the lid. The entire coated area of the envelope (1·8 cm²) was heated progressively using 40 pulses at the rate of about one pulse per minute. This was achieved automatically, switching the arc by means of a process timing circuit. The tube was moved manually between pulses, using a mechanical device to index the firing positions. This whole operation could, of course, be mechanised. The proportion of getter material transferred from the envelope to the condenser disc was found by subsequent weighing to be 80 - 100 per cent.

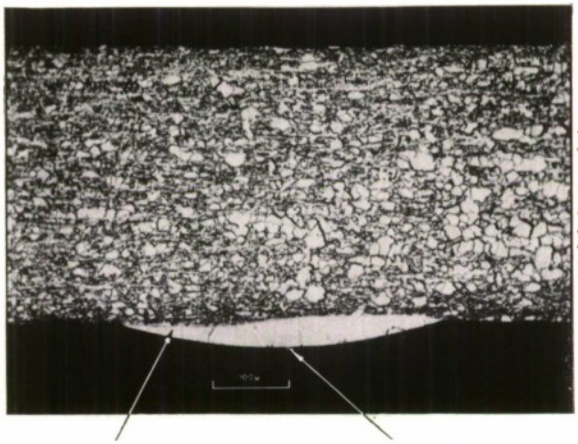

FIG. 2. Section of argon arc pulsed molybdenum lid showing re-crystallization 2·5 sec. standard pulse.

It was necessary to evaporate at least 80 per cent of the thulium film off the envelope in order to avoid producing particles on the lid. In the test tubes the molybdenum getter condenser had a nickel rim which enabled it to be moved within the tube by means of an external magnet. Thus the condenser could be moved out of the way to enable the thulium film on the lid to be inspected at all stages, without the need for breaking vacuum.

The flat glass window was large enough to permit the use of a binocular microscope for this purpose. Inspection was carried out before and after getter firing, and also after gas sorption measurements.

After firing the getter, the condenser was turned round so that the condensed thulium film could be microscopically examined. This and subsequent tests performed after opening the tube showed that the condensed film was always extremely adherent, even after saturation with the test gases.

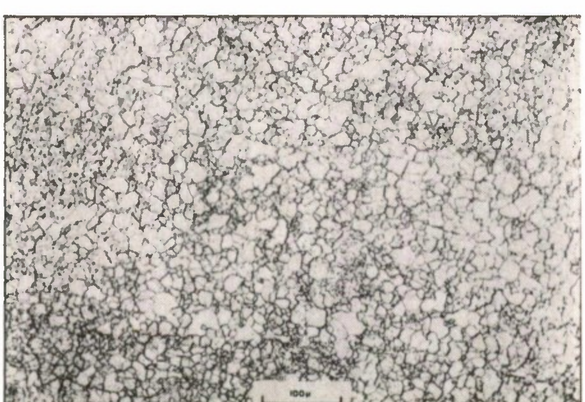

FIG. 3. Section parallel toplane of molybdenum lid at a depth of about 0·003 in. from the side on which the arc was struck. 2·5 sec. standard pulses.

The getter was fired either while the tube was still being pumped, or after seal off. On a system whose background pressure was about 3×10^{-6} torr, it was shown that there was no difference in gas sorption capacities between the two methods. However, a quantity of argon (0·01 to 0·02 cm^3 torr) was evolved during the firing of a getter, as shown by mass spectrometer measurements. It is therefore advisable to fire the getter while the tube is still on the pump, so that this gas can be pumped away before the tube is sealed off. Shelf tests over a period of 18 months have shown that subsequent diffusion of argon, if any, is less than $1{\cdot}5 \times 10^{-3}$ cm^3 torr per year. Other envelope heating techniques would not introduce argon during firing.

Structure of Molybdenum. At the firing temperatures used here, it was to be expected that re-crystallization of the molybdenum envelope would take place. It was necessary to ensure that the envelope would not become so brittle as to produce cracks or leaks. A large number of firing spots were therefore sectioned and examined microscopically. Although the molybdenum was found to have been partly recrystallized, in no case was any cracking observed.

Fig. 2 is a section perpendicular to the plane of the lid. The crescent-shaped white region on one side represents the eutectic alloy formed between the molybdenum lid and its nickel plating where the arc was struck. This is discussed more fully in the Appendix.

Fig. 3 is a section parallel to the plane of the lid, at a depth of about 0·008 cm. from the arc side of the lid.

As an additional confirmation, thulium getter tubes were leak checked to a lower detection limit of 2×10^{-9} cm^3 torr/sec, for 50 firing spots and to 3×10^{-8} cm^3 torr/sec for 300 firing spots. No leaks were found.

Getter Sorption Measurements

Experimental Method. Fig. 4 illustrates the apparatus used to measure the sorption properties of the getters. The tube, with fired getter, is joined *via* its breakseal, S, to the pumping system as shown. The system is pumped as far as the intact breakseal, the components within the dotted rectangle (metal taps MT1 and MT2, Pirani gauge P, steel ball B and glass capillary leak L) being baked at 450°C for half an hour.

When cool, MT1 and MT2 are closed, the breakseal, S, is fractured with the aid of the steel ball B. A known pressure of the test gas, usually 5 to 15 torr, is prepared in the gas reservoir. GT1 is shut and MT1 opened, so admitting the gas to the

getter measurement volume V at a known rate (10^{-3} cm^3 torr/sec was the value normally used).

The pressure P_g(torr) in the getter measurement volume V (cm^3) at any time t (secs) is given by the following equation:

$$q = S_g P_g + V(dP_g/dt) = v + V(dP_g/dt)$$

where q = quantity of gas entering in unit time through the capillary (cm^3 torr/sec)

S_g = "gettering rate" as defined by Wagener[2] (cm^3/sec)

v = "sorption velocity" as defined by della Porta and Ricca[3] (cm^3 torr/sec).

The quantity, q, has a known constant value throughout each experiment. This is because:

(a) The pressure, P_r, in the gas reservoir is very large compared with P_g, so that flow of gas into the measurement volume through the capillary (proportional to P_r) is very large in comparison with the flow outwards (proportional to P_g). Hence, though the rate of outflow of gas increases as P_g rises, it remains negligible in relation to the inflow.

(b) P_r remains substantially constant, as the quantity of gas in the reservoir is very large compared with that removed by getter sorption.

(c) The capillary leak rate, q, is checked at the beginning of the experiment and after saturation of the getter, to verify that no partial blockage has occurred.

As saturation of the getter approaches, there is a tendency for the gettering rate, S_g, to decrease. The resulting rising value of P_g is followed on the Pirani gauge.

In some cases the rise of P_g was measured on an ionization gauge which was made part of the getter test tube. The gauge had a rhenium filament and was operated at $0{\cdot}05\mu A$ electron emission current so that the pumping speed of the gauge was negligible relative to that of the getter. In these experiments the gettering rates were measured for pressures between 10^{-5} and 10^{-2} torr.

Test gases of spectroscopic purity were used throughout the experiments except in the case of methane and air. This, together with the fact that the test gas in the reservoir was at a pressure exceeding 5 torr, should reduce the partial pressures of impurities arising from outgassing of the unbaked reservoir to negligible proportions.

Saturation Criterion. The capacity of the getter for each gas under test was defined as the quantity of gas after whose sorption, the gettering rate, S_g fell to a minimum acceptable value. This depends on the application for which the getter is required. The value 0·2 cm^3/sec applies throughout this paper.

Provided $VdP_g/dt << S_g P_g$ the equation given above can be written approximately: $q = S_g P_g = v$.

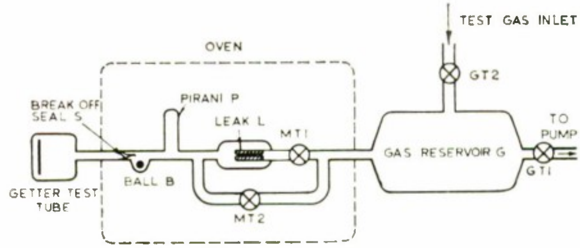

FIG. 4. Getter sorption measurement apparatus.

In these circumstances, therefore, using $q = 10^{-3}$ cm^3 torr/sec, and $S_g = 0{\cdot}2$ cm^3/sec, we see that saturation corresponds to the point at which P_g has risen to $5{\cdot}10^{-3}$ torr, a pressure conveniently measured on the pirani gauge. Normally, the value of the capacity determined on this criterion is between 60 per cent and 90 per cent of that obtained by complete saturation, *i.e.*, until the getter ceases to absorb at a measurable rate.

Gettering of Combinations of Gases. Each getter in a vacuum tube encounters in practice a number of different gases, either simultaneously or in succession. Some gases such as oxygen, nitrogen and the oxides of carbon probably do not diffuse far into the bulk of this type of getter and for these saturation probably occurs when all vacant sites at or near the surface have been occupied. Thus a surface barrier to the sorption of further gas may be set up. Hence it is obviously of limited value to know for example that a particular getter had an enormous capacity for hydrogen without also knowing whether or not the prior (or simultaneous) sorption of a little oxygen, let us say, reduces the hydrogen sorption to a negligible quantity. For example Fransen and Perdijk[4] showed that prior saturation of a barium film with carbon monoxide prevented the subsequent take up of any detectable amount of either hydrogen or nitrogen, whereas the unprejudiced capacity for hydrogen greatly exceeds that for carbon monoxide.

It is therefore important, for the assessment of a getter system, to include tests in which a given getter sample is exposed to a number of different gases, either together or in succession. Very little information of this sort is available for barium getters.

In the tests on the rare earth getter system each getter test tube was used to measure the sorption properties of a succession of different gases. That is, having determined the gettering rate as a function of sorbed quantity for a given gas (until the gettering rate had fallen to a predetermined value, usually 0·2 cm^3/sec), this was then pumped away and a second gas was introduced. This was then treated similarly and followed by a third or even

fourth gas. The gases suspected of a getter passivating effect were, in general, admitted in advance of hydrogen, which was known to diffuse readily into the bulk of rare earth metal films in the absence of passivation.

It must be recognized that the sorption capacities for successively admitted gases are probably less than if each gas were exposed to a fresh getter sample.

Results

Getter Capacities. Sorption capacity measurements have been made on 30 tubes containing thulium and seven tubes containing samarium getters fired by the system described. Each tube was given one of two types of test, the two types differing in the combination of test gases admitted. The results are summarized in the next two sections.

It is stressed that the sorption capacities quoted are cumulative, as explained earlier. Saturation of the getter by individual gases would be expected, in general, to yield higher capacities.

The test conditions are summarized below:

Average weight of getter film on envelope	=18 mg
Area of getter film on envelope	=1·8 cm^2
Area of condenser disc	=5 cm^2
Distance of condenser disc from envelope film	=0·5 cm
Average weight of getter transferred to condenser disc	=16 mg
Test gas admission rate, q	=10^{-3} cm^3 torr/sec
Getter " saturation " criterion: gettering rate, S_g	=0·2 cm^3/sec

Capacities: Comparison with Barium. Evaluation of the new getters should include a comparison with conventional barium getters. This is difficult, however, as the published sorption measurements on barium getters have been made under widely varying conditions on films of greatly differing (and sometimes unspecified) area and thickness. Moreover there has been no standardization on what is meant by such terms as " saturation " and " capacity ". However, to permit some sort of comparison to be made Table V has been prepared. This summarizes the more recently published values of the sorption capacity of barium films for a number of gases. To achieve a degree of standardization, the capacities have been normalized to a single weight of barium (*i.e.*, 4 mg).

The envelope getter scheme lends itself to the evaporation of considerably greater weights of active material than could be fired from a conventional barium getter by the passage of an electric current *via* an insulated lead through the tube envelope. Thus a comparison of capacities are not made on an equal weight basis. For a tube of the

TABLE I. Test Type I (Thulium).
Cumulative Sorption Capacities for Successively Admitted Cases (Thulium).

Order of Admission	*Gas*	*Quantity of gas sorbed (cm^3 torr)*	*Whether " saturated " to S_g=0·2 cm^3/sec*
1	Air* (undried)	30	Yes
2	Hydrogen	100	No
3	Oxygen	20	Yes

*If, instead of moist air, dry nitrogen was admitted, " saturation " occurred after the sorption of about 25 cm^3 torr. Subsequent admission of 5 cm^3 torr of dry oxygen at this stage did not cause saturation. The behaviour in stages 2 and 3 of the test was as given in Table I.

TABLE II. Test Type 2 (Thulium).
Cumulative Sorption Capacities for Successively Admitted Gases (Thulium).

Order of Admission	*Gas*	*Quantity of gas sorbed (cm^3 torr)*	*Whether " saturated " to S_g=0·2 cm^3/sec*
1	Methane	0	–
2	Hydrogen	30	No
3	Carbon monoxide	10	No
4	Hydrogen	30	No
5	Carbon dioxide	10	No
6	Hydrogen	30	No

TABLE III. Test Type I (Samarium).
Cumulative Sorption Capacities for Successively Admitted Gases (Samarium).

Order of Admission	*Gas*	*Quantity of gas sorbed (cm^3 torr)*	*Whether "saturated" to $S_g=0{\cdot}2$ cm^3/sec*
1	Nitrogen	6	Yes
2	Hydrogen	100	No
3	Oxygen	6	Yes

TABLE IV. Test Type 2 (Samarium).
Cumulative Sorption Capacities for Successively Admitted Gases (Samarium).

Order of Admission	*Gas*	*Quantity of gas sorbed (cm^3 torr)*	*Whether "saturated" to $S_g=0{\cdot}2$ cm^3/sec*
1	Methane	0	–
2	Hydrogen	60	No
3	Carbon Monoxide	10	Yes

size shown in Fig. 1, it is suggested that a reasonable size of Kic type getter tube fired by this means would give a 4 mg yield of barium, and therefore this should be compared with the 15-20 mg thulium or samarium film fired off the envelope, and whose properties are summarized in Tables I to IV. These weights do not, of course, represent the upper limit of either getter system.

In comparing the gas sorption properties of the two types of getter it must be stressed that the figures given for the envelope scheme are for successive gases on the same sample, and are not, in general, the saturation capacities for individual gases. There are no similar published figures for barium.

With this reservation in mind, it may be tentatively concluded that the sorption capacity of the new thulium/envelope system is greater than that achieved by conventional barium getters for nitrogen, roughly equal to barium for the oxides of carbon and less for oxygen. Saturation values have not yet been measured for hydrogen. The importance of the nitrogen capacity lies in the fact that nitrogen constitutes four-fifths of an atmospheric leak.

A comparison between the measured gettering rates of the thulium getter and of a conventional barium getter is given in Fig. 5. Graph (A) shows gettering rate as a function of the absorbed quantity of hydrogen for a 3·6 mg thulium getter,

TABLE V. Sorption Capacities for Barium Getters (4 mg)

Gas	*Apparent area of film (cm^2)*	*Capacity at 20°C (cc torr)*	*Reference*
O_2	Indep of area	276 ± 36	5
	40	200	9
	Indep of area	264	Theoretical for complete conversion to BaO
N_2	22 – 220	19·4	8
	40	13·2	9
	100	10·0	7
	Not stated	15	10
H_2	Indep of area	512 ± 28	5
	40	179	9
	Indep of area	532	Theoretical for complete conversion to BaH_2
CO_2	40	24	9
CO	Indep of area over wide limits	48	6
	88	17·6	7
	40	28·8	9

fired as already described, while graph (B) gives similar information for a 3 mg barium "Kic" type getter fired on to a glass surface of area about 2 cm^2. In each case the hydrogen was admitted to the getter tube at $9{\cdot}6 \times 10^{-3}$ cm^3 torr/sec.

With both types of getter the flow of hydrogen was stopped after the sorption of 90 to 100 cm^3 torr. After this, nitrogen was leaked in and while the thulium typically absorbed about 6 cm^3 torr of nitrogen, with an initial gettering rate of about 30 cm^3/sec, the barium did not always absorb any nitrogen, and if it did, the initial gettering rate was about 2 cm^3/sec.

These results indicate that the thulium getter sorbs both hydrogen and nitrogen with a greater speed than does barium.

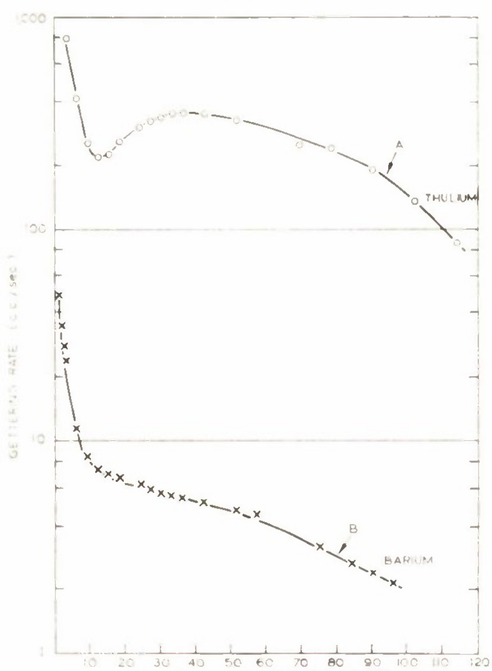

Fig. 5. Gettering rates for Tm and Ba as a function of D_2 sorbed (Tm—3·6 mg on area 5 sq cm).
(Ba—3 mg on area 2 sq cm).

Acknowledgements

The idea for the new getter system arose out of discussions between the authors and Mr. R. Redstone.

Appendix

Firing techniques—discussion.

The vapour pressure data quoted earlier[1] suggests that both samarium and thulium could be evaporated within two seconds at a steady temperature of 1,000°C. However, the constant power input level required to maintain 1,000°C for two seconds would result in a very long warm up time to that temperature, with consequent excessive heat spread to other parts of the tube. The standard firing pulses so far employed, which reach instantaneous peak temperatures of 1,300°C-1,500°C, are the result of the necessity for rapid warm up. In the ideal firing pulse, the power input would be at two levels. Initially it would be at a high level, heating to 1,000°C rapidly, whereupon, it would be switched automatically to the lower level required to maintain that temperature, for about two seconds. This type of pulse may help in the firing of getters from envelopes other than molybdenum.

A technique used to verify the fact that the envelope has reached a specified minimum temperature during each pulse, utilizes the fact that molybdenum and nickel have a eutectic alloy of melting point 1,315°C. The outside of the lid is plated with nickel to a depth of 0·001 to 0·0013 cm. After the firing of a normal arc, a smooth, bright circle is left on the lid, indicating the region in which the eutectic alloy has melted. Examination of about 500 firing spots showed that over 90 per cent of arc pulses produce satisfactory evaporation. As there is a large number of pulses per tube, the probability of inadequate firing is very low. In any case, an unsatisfactory pulse can always be detected externally by examination of the eutectic circles, and if necessary, a repeat pulse fired. In practice it is found that 80-100% of the getter is reliably transferred from the envelope to the condenser disc.

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ANALOGUE COMPUTER SOLUTION OF DECOMPRESSION

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The need to restrict the rate at which man can reduce the ambient pressure surrounding him in order to avoid the symptoms of Decompression Sickness is a well recognized stricture on the freedom of aviators, divers, caisson workers and hospital staffs engaged in hyperbaric facilities, and not least those whose activities require ascent to altitude following exposure to higher pressures than atmospheric.

The first rational approach to the problem of decompression was that of Haldane *et al.* [1] in 1908 who constructed ascent schedules based on the premises:

(a) that inert gas exchange from the body could be mathematically represented by considering a minimum of four parallel compartments to each of which a specific half-time could be ascribed, and

(b) that the body could tolerate a degree of supersaturation without symptoms.

The constants used by Haldane *et al.* have been modified over the intervening years, as the scope and accumulated experience of diving has increased, but essentially this mathematical solution for decompression has been used to evolve the decompression tables in current use throughout the world.

Four years ago studies by the Canadian Forces Medical Services at Toronto, directed at the future of deep diving and deep submarine techniques, reached the point where the problem of decompression remained the most difficult to solve using current tabular methods. It was appreciated that to provide optimum flexibility to the future diver consistent with safety, some form of analogue computer sensing the actual pressure-time history was required. Such a computer should continuously provide a decompression solution appropriate to the exposure history.

Work was directed to investigate simultaneously various forms of analogue computers using pneumatic, hydraulic and electrical signals. The pneumatic version had many advantages, being small, simple, rugged and requiring no energy other than that provided by the inspired gas[2].

Analysis of current decompression tables in terms of the Haldane concept of four parallel compartments having half-times of 10, 20, 40 and 80 minutes was made mathematically and by a pneumatic analogue to derive a range of supersaturation ratios: the ratio between theoretical tissue inert gas pressure and ambient pressure

$$\left(R = \frac{P_{T_N}}{P_A}\right)$$

Laboratory tests with a pneumatic analogue computer calibrated with the constants obtained showed that the theoretical formulae could be satisfied by following a continuous ascent path of compound exponential shape. Since the decompression solution at any instant was derived directly from the preceding pressure history it followed that subsequent exposures, or repetitive dives, should result in decompression information of equal validity.

For the diver, prototype pneumatic analogue computers were constructed to display ambient depth and safe ascent depth on the same scale. When the diver required to ascend, the correct ascent profile was followed by adjusting ambient depth to correspond at all times with the ascent depth generated continuously by the computer.

Some sea dives were carried out, but in order to gain a wide experience with large numbers of subjects under the precise control necessary for careful evaluation, most exposures were simulated in a hyperbaric chamber.

The first series of exposures reported [2] were those using the so-called Mark II P pneumatic

analogue computer designed deliberately to produce decompression profiles as close to the limiting threshold for man as the existing data allowed. Thus this computer was calibrated with four parallel compartments of 10, 20, 40 and 80 minute half-times with supersaturation ratios ($P_{T_N}/{}^{P}A$) of 2·65, 2·15, 1·85 and 1·65 respectively. The range of dives carried out is shown below in Table 1.

Once the validity of the method had been demonstrated *in vivo*[2], a second series was undertaken with the Mark III P pneumatic analogue computer calibrated with half-times of 20, 40, 80 and 160 minutes and a common supersaturation ratio of 1·6 : 1. These constants were selected from a preceding analysis to eliminate the anomaly of differing ratios being ascribed to specific but arbitrarily chosen compartment half-times, and to provide a greater margin of safety [3].

While the concept of regarding the body as being represented by four parallel compartments had empirical justification, it seemed more likely that in practice the transfer of inert gas to and from the body resembled a cascade or series system, or a combination of both.

It was demonstrated that each configuration had an exact mathematical equivalence [4]. From a technical point of view there were advantages in considering a series system and later work concentrated attention here.

Accordingly prototypes, identified as Mark V S computers, were constructed with four compartments in series each with a half-time of 21 minutes and a common supersaturation ratio of 1·44 : 1. The range of dives made using this computer is shown in Table 1.

While the earlier construction of decompression tables was based on the assumption that the

TABLE 1. Pneumatic Analogue Decompression Computer. Incidence of "Bends" During Trials July 1963-August 1966 Single and Repetitive Dives

Model	*Mark II P*	*Mark III P*	*Mark V S*
Compartment Configuration	4 Parallel	4 Parallel	4 Series
Time Constants (mins.)	10 20 40 80	20 40 80 160	21 (common to all compartments)
Supersaturation Ratio $\left(\frac{P_{T_N}}{P_A}\right)$	2·65 2·15 1·85 1·65	1·6 (common to all compartments)	1·44 (common to all compartments)
Scope of Dives	300′ – 20 mins. 70′ – 12 hours	250′ – 80 mins. 150′ – 4 hours	
No. of Subjects	39	15	66
Age range	22 – 56	19 – 47	18 – 44
No. of Dives	523	478	1680
Type of "Bend" II	6	2	–
Type of "Bend" I	20	5	6
Percentage Incidence	5·0	1·5	0·4

processes of inert gas uptake and elimination were symmetrically equal, Hempleman [5] produced evidence in animals that strongly suggested these two processes were not symmetrical. The need for empirical correction of the earlier diving tables over the years can be attributed to a similar mechanism occurring in man. Following prolonged or complicated dive patterns in our series, it was found that the solution offered by the pneumatic analogue computers differed significantly from that derived from mathematical or electrical analogues which treated inert gas exchange as a symmetrical process.

The *in vivo* trials with the pneumatic computer left no doubt that its inherent asymmetry was operating in the same sense as that presumed to occur in man. The parameters of this asymmetry has been described elsewhere [3].

Further work is necessary to establish the constants appropriate for the saturation case, *e.g.*, for an exposure of infinite duration, but for all practical purposes using compressed air, the Mark V S pneumatic analogue computer provides a flexibility, economy and safety for divers not available hitherto.

The computer was originally conceived in order to provide instantaneous decompression information for exygen-helium diving when complicated dive profiles and wide variation of gas mixtures would render the traditional tabular approach to decompression hopelessly inadequate. Because excellent data is available following air diving, the principle of computer controlled decompression was first applied to diving using air. The literature concerning decompression following helium diving is of course not nearly as reliable, and conclusions drawn from analysis of this data must be guarded.

Bench experiments suggested that the Pneumatic Analogue Computer could provide a valid decompression following exposure to an oxygen-helium mixture. The decompression profile for oxygen-helium diving differs radically from that generated from an air dive of similar depth-time dimensions.

To confirm this, decompression from a series of dives using oxygen-helium mixtures was controlled by a computer calibrated with the same constants as those derived for air diving. It became apparent that the concept was a valid one (1·0% incidence of decompression sickness). While only 200 dives of this type have been made, the results suggest that the threshold for Helium decompression is more critical than for nitrogen; more work is necessary to determine the parameters of this threshold, and some small adjustment of computer constants may be necessary to achieve the high probability of symptom free dives obtained following air dives (99·7%).

Even so, the same computer appears to give an appropriate decompression profile from either air or oxygen-helium dives, and a series of repetitive dives in which the gas breathed is alternated at random.

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H.R.H. The Duke of Edinburgh accompanied by Dr. J. L. King, Chief Scientist, and Mr. J. R. F. Moss, Superintendent, during his visit to the Naval Construction Research Establishment on October 12, 1967.

BRITTLE FRACTURE OF STEEL, AND ITS IMPLICATIONS

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ABSTRACT

The historical background to structural failure attributed to brittle fracture of steel, and factors influencing its occurrence, are described, and the meaning of test data in terms of design and operational requirements is discussed with particular reference to low temperature use. A possible relationship between slow and fast fracture is observed, and current developments in steel and associated welding technology to provide wider safety margins, in spite of higher specific strengths, are surveyed. A need for closer links between dislocation theory, fracture mechanics, design, and technology is called for, and practical limitations to metallurgical integrity are put into perspective.

Introduction

Extreme conditions as far as military structures and weapons are concerned can be interpreted as extreme cold, high temperature, deep submergence in the sea, intense radiation, high speeds, particularly corrosive or erosive environments, high fatigue stress and fast rates of loading. The performance of materials is affected by most of these factors, but as steel is by far the most commonly used, and is one of the most sensitive to reduced temperature, the paper deals almost exclusively with the problems which must be considered in its use for military purposes under conditions imposed by advanced warfare.

The range of equipment for which steel is the obvious choice is very wide indeed, ranging from the hulls and power plants of deep diving submarines, through the requirements of both land and airborne fighting vehicles, to lightweight high-strength bridges. Its design demands a critical combination of properties, amongst which are specific strength (*i.e.* strength to weight ratio), fabricability (usually by welding), fatigue and corrosion resistance and toughness. Of the extreme conditions listed, the most serious as far as steel is concerned are low temperatures, fatigue (especially in the high stress low endurance range), and the high rates of strain associated with explosive or projectile loading. Each of these influences has to be considered to a greater or lesser degree in the design of military equipment, and on the anticipated operational performance of the steel used.

While brittle fracture cannot now be considered as a major problem in Naval surface ships, the information which has been derived from research programmes is of broader interest to other military structures and the following is therefore a general appreciation of current knowledge, and the limitations to design imposed by known metallurgical factors.

Firstly, the design of equipment and the choice of steel must be based upon the close identification of conditions under which it has to operate in order to achieve maximum economy in weight and expense, and to ensure reliability particularly where subsequent field maintenance may be difficult. While mild steel is capable of considerable abuse because of its ductility, this property suddenly disappears as the temperature is lowered so that under shock loading or high stressing, sudden and sometimes catastrophic brittle fracture may occur. Examples of such instances are given in Figs. 1 and 2. Brittle fracture in steel has been experienced since it was first used as a structural material, although the nature and cause of early failures was not appreciated. The spectacular and disturbing effects of some failures have resulted in outbursts of research activity to discover its cause since the middle of the nineteenth century. For example, *The Engineer* of June 1861 discusses

FIG. 1. Bow Section of " World Concord " in the Irish Sea.

" The Effect of Percussion and Frost upon Iron ". It is partly true to say that the problem of brittle fracture remained a mystery until the need for large welded structures, and several gross instances of catastrophic failure, sometimes with loss of life, generated intense activity, particularly over the past three decades. Now, the basic causes are fairly well understood, and with the aid of semi-empirical tests, designers and steel producers are able to guarantee safety under reasonably normal conditions.

The first requirement is to establish the temperature at which steel becomes brittle. This depends upon the steel composition and conditions, but the phenomena can be determined by relatively simple impact tests carried out at progressively reduced temperature levels. Fig. 3 shows the typical transition from toughness to brittleness of mild steel with an associated drop in energy absorption capacity, and a change in fracture appearance from fibrous to crystalline over a temperature range, as determined by the Charpy test. The temperature range and the energy absorption levels are a function of the steel composition and constitution in which plate thickness plays an important rôle, internal flaws, prior strain history, rate of loading, length of uninterrupted potential crack path, the rate at which energy can be fed to the advancement crack tip, and the effect of environmental history such as irradiation damage or surface corrosion processes. Literature on the various aspects of brittle fracture is copious and reference to a few useful surveys is given in References [(1), (2), (3), (4)].

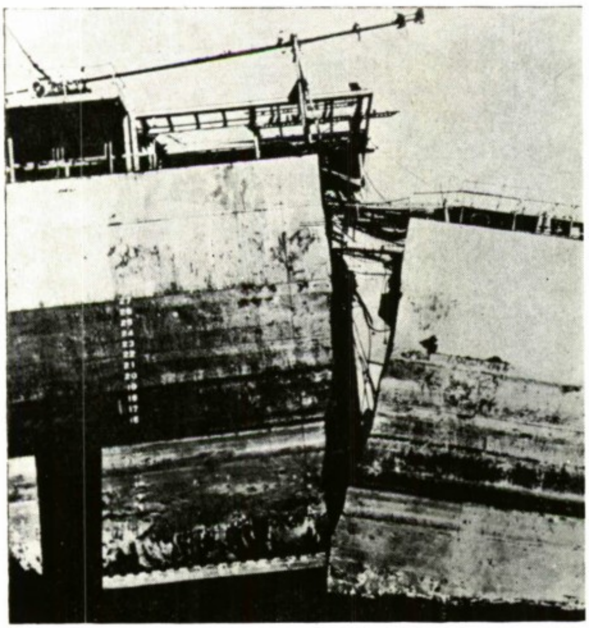


FIG. 2. Fracture of U.S.S. " Schenectady ".

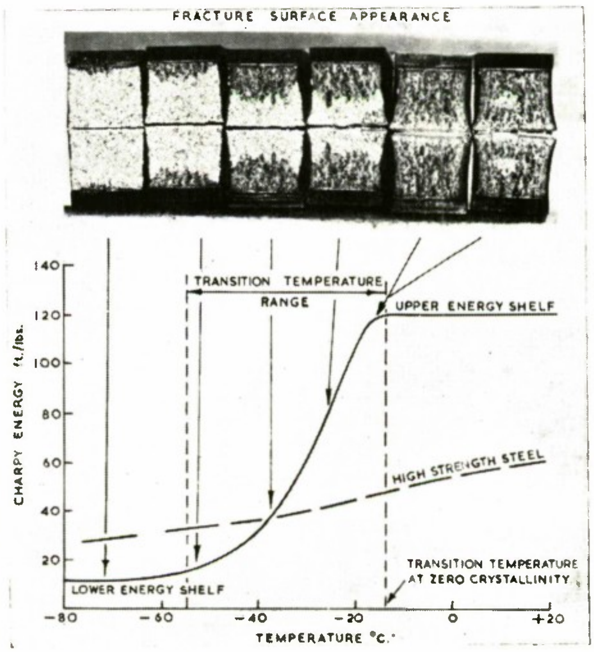


FIG. 3. Tough to Brittle Transition Phenomena in Structural Steel.

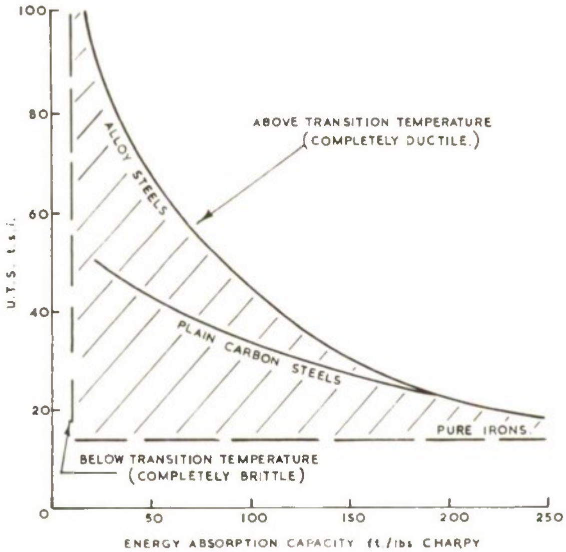


FIG. 4. General Relationship Between Ultimate Tensile Strength and Energy Absorption Capacity of Steels.

Effect Of Steel Composition and Constitution

The chief factors influencing the choice of steel for a particular application are adequate strength level commensurate with sufficient fatigue and shock resistance, and the availability of satisfactory production processes. While a wide range of steels, with ultimate tensile strengths up to 100 t.s.i. and beyond are readily available, they do not always possess the desired degree of toughness. The characteristics of toughness, or energy absorption, particularly at stress concentrators such as notches, drops considerably with the increased strength which is achieved by alloying or heat treatment. It is therefore necessary to equate the results of toughness tests on steels to the type of service expected from them in the field. The transition curve for steel shows two distinct energy absorption levels; broadly speaking, the lower one may be considered as the energy required to initiate cracking, and the upper one the energy to give failure irrespective of the mode. More highly alloyed steels give a flatter transition temperature range to the point where there is a broadly linear relationship between energy and temperature. Thus a general idea of the relationship between strength achieved by alloying and thermal treatment, energy absorption capacity, and transition temperature, may be seen from Figs. 4 and 5.

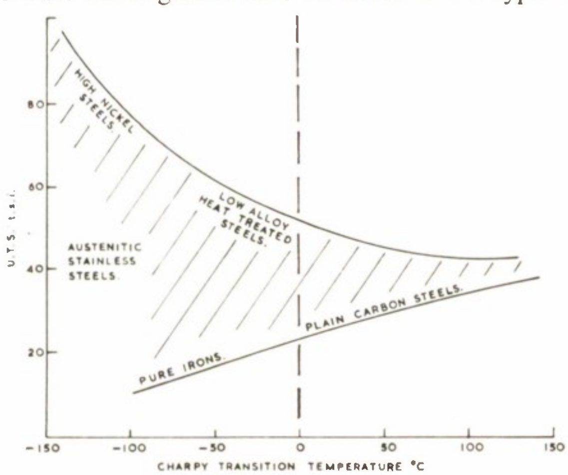


FIG. 5. General Relationship between Ultimate Tensile Strength and the Onset of Brittleness in Steels with Respect to Temperature.

It is beyond the scope of this paper to discuss in detail the various metallurgical factors responsible for the relationship between strength, transition temperature and toughness, but grain size, micro-structure, homogeneity and impurity content (*e.g.* gases) are of obvious significance. Considerable improvements in deoxidation practices and grain refinement during steel production have led to lower incidence of brittle fracture over the past decade, but much still remains to be achieved, particularly in the field of low alloy steels. The effect of steel thickness is of importance also, since the degree of heterogeneity, and hence transition temperature is adversely affected by increasing thickness.

The inclusion by steel producers of Charpy tests in their production control test procedure has done much to improve the toughness levels in steels, but further significant improvement is closely linked to high capital investment.

Welding Development

With the increasing strength achieved in steel plate and rolled sections, the problems of achieving sound welds in fabricated structures by manual and semi-automatic processes become more

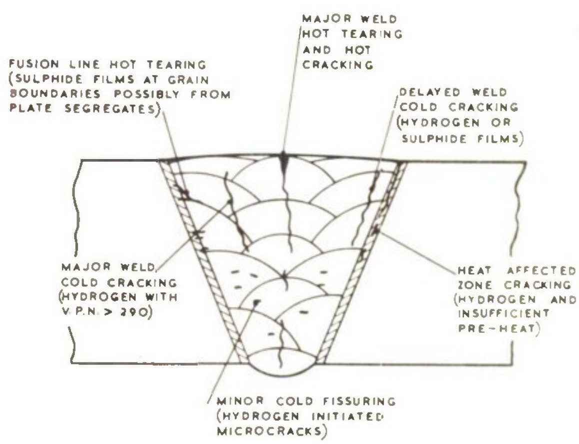


FIG. 6. Forms of Cracking which may be Experienced in Weldments.

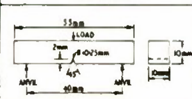
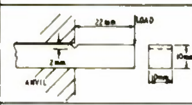
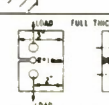
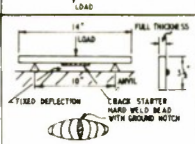
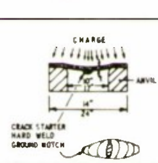
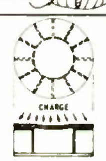
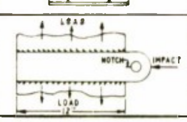
FIG. 7. Hydrogen Cracking Experienced in Parent Steel in the Weld Heat-affected Zone.

acute(5). The chief form of unsoundness lies in the development of sub-surface cracks, some of which are difficult to detect by non-destructive testing methods, but which nevertheless introduce zones of weakness and thus contribute to low energy absorption and brittle fracture.

Chief forms of weld cracking which are shown in Fig. 6 are: (a) hot tearing, associated with low ductility over critical cooling ranges whilst the weld deposited metal is under cooling restraint; (b) hydrogen cracking, which occurs as a result of hydrogen in the weld pool and parent metal migrating to sensitive heat affected areas in the parent plate, where it gives rise to the sharp fissuring illustrated in Fig. 7; (c) the existence of low melting point eutectics from impurities (particularly sulphur) and hence planes of weakness, in the grain boundaries.

Greater understanding and control of these factors, both in the choice of parent plate steel and weld rod compositions, and finer control of welding practice (*i.e.* use of low hydrogen electrode fluxes, critical degrees of preheat, and minimum restraint) is leading to a reduced number of these

FIG. 8. Comparison of Various Tests Commonly Used to Determine the Toughness of Structural Steels.

TEST	GEOMETRY	LOADING	RATE OF LOADING	MECHANICAL MEASUREMENTS	OTHER MEASUREMENTS	ADVANTAGES	DISADVANTAGES
CHARPY		THREE POINT BEND. LOAD APPLIED BY MEANS OF FALLING PENDULUM, FLYWHEEL, OR TUP.	SLOW OR IMPACT 16·8Ft./Sec. (CHARPY) →200Ft./Sec. (N.C.R.E.)	ENERGY ABSORBED, LOAD, AND DEFLECTION	% CRYSTALLINE APPEARANCE IN FRACTURE. DEFORMATION. (SEE FIG. 3)	EASY TO CARRY OUT. UNIVERSAL USAGE.	RESULTS APPLY TO LOADING SYSTEM USED AND ARE SENSITIVE TO GEOMETRY, NOTCH AND IMPACT SPEED.
IZOD		CANTILEVER BEND. LOAD APPLIED BY MEANS OF FALLING PENDULUM.	IMPACT 11Ft./Sec.	ENERGY ABSORBED DURING IMPACT	% CRYSTALLINE APPEARANCE IN FRACTURE. DEFORMATION.	EASY TO CARRY OUT. BLOW REMOTE FROM FRACTURE.	USED ONLY IN U.K. LESS SENSITIVE TO LOW ENERGY MEASUREMENT THAN CHARPY. HAS ALL CHARPY DRAWBACKS.
NAVY TEAR		COMBINED TENSION AND BENDING IN STANDARD TENSILE TESTING MACHINE.	SLOW AT UNIFORM RATE.	ENERGY TO INITIATE AND PROPAGATE FRACTURE.	% CRYSTALLINE APPEARANCE IN FRACTURE. DEFORMATION.	EASY TO CARRY OUT. FULL THICKNESS. CRACK PROPAGATES AS IN A CATASTROPHIC FAILURE.	RESULTS APPLY TO LOADING SYSTEM USED AND WOULD BE SENSITIVE TO ALL CHARPY DRAWBACKS.
PELLINI DROP WEIGHT		THREE POINT BENDING LOAD APPLIED BY MEANS OF FALLING WEIGHT.	IMPACT 32Ft./Sec.	NONE CERTAIN OF THE ABOVE MAY REQUIRE COMPLEX INSTRUMENTATION.	TEMPERATURE AT WHICH FRACTURE OCCURS WITH A SINGLE BLOW OF FALLING WEIGHT (SEE FIG. 3)	EASY TO CARRY OUT. FULL THICKNESS GIVES MEASURE OF RESISTANCE TO CRACK PROPAGATION.	RESULTS APPLY TO LOADING SYSTEM USED AND ARE ONLY INSENSITIVE TO NOTCH AND IMPACT SPEED IN ABSENCE OF DUCTILITY.
PELLINI CRACK STARTER BULGE		TRIAXIAL. LOAD APPLIED EXPLOSIVELY AT GIVEN STAND-OFF.	FAST, AIR LOADING.	SHOCK FACTOR $\left(\frac{\sqrt{\text{CHARGE WT}}}{\text{STAND-OFF}}\right)$ DEFLECTION	LENGTH OF CRACKS. DEFORMATION. FRACTURE APPEARANCE (SEE FIG. 3)	FULL THICKNESS. SEVERE RATE OF LOADING GIVES MEASURE OF RESISTANCE TO CRACK PROPAGATION.	RESULTS APPLY TO LOADING SYSTEM USED AND ARE ONLY INSENSITIVE TO NOTCH AND IMPACT SPEED IN ABSENCE OF DUCTILITY
PADDLE WHEEL TARGETS		TRIAXIAL. LOAD APPLIED EXPLOSIVELY AT GIVEN STAND-OFF. REALISTIC RESTRAINTS CAN BE BUILT IN.	FAST, WATER LOADING.	SHOCK FACTOR DEFLECTION.	LENGTH OF CRACKS. DEFORMATION. FRACTURE APPEARANCE.	FULL THICKNESS, LARGE SIZE GIVES MEASURE OF UNDERWATER EXPLOSION RESISTANCE. SUITABLE FOR CUMULATIVE DAMAGE TESTS.	RESULTS APPLY TO LOADING SYSTEM AND RESTRAINTS USED. STAND-OFF AND SHOCK FACTOR GOVERN DAMAGE.
ROBERTSON		UNIAXIAL LOAD APPLIED IN SPECIAL RIG. CRACK STARTED AT COOLED NOTCH BY IMPACT & RUNS (1) INTO PROGRESSIVELY INCREASING TEMP. (2) INTO PLATE AT CONSTANT TEMP.	CRACK PROPAGATES AT NATURAL RATE.	NOMINAL STRESS.	TEMPERATURE. DUCTILE ARREST (SEE FIG. 3).	TYPIFIES CASE OF CRACK PROPAGATION THROUGH STRUCTURE PRE-LOADED IN TENSION.	RESULTS APPLY TO LOADING SYSTEM USED. DO NOT APPLY IF METAL IS YIELDING AT A FAST RATE AHEAD OF CRACK.

flaws and hence to weldments less prone to brittle failure. Nevertheless, further advancements in test procedures, including non-destructive methods are required if the extreme conditions of warfare are to be met.

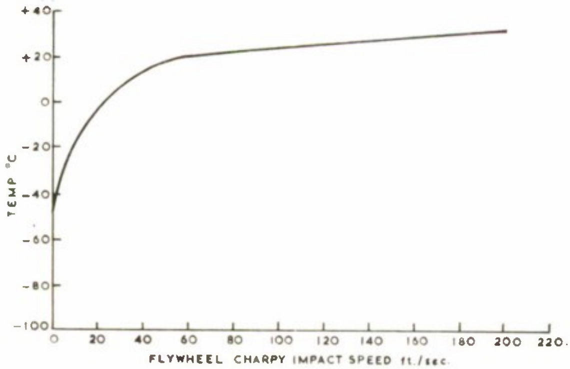


FIG. 9. Relationship Between Rate of Loading and the Temperature Dependence of Brittleness in a Low Alloy Steel.

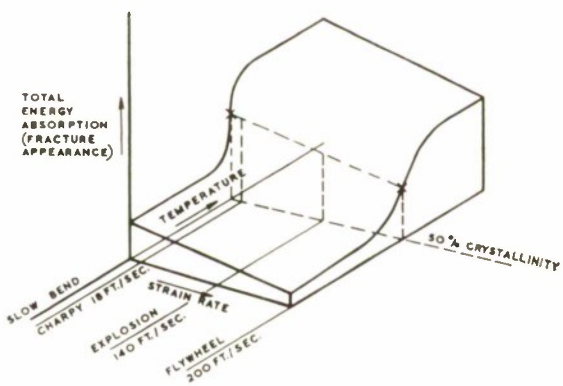


FIG. 10. The Combined Effects of Strain Rate and Temperature on the Energy Absorption Capacity of a Structural Steel.

Limitations of Test Data

It is necessary to be able to equate the results of simple tests to the performance of actual structures in service in order to facilitate optimum material selection, and more research effort is required in this direction. For example, the hulls of deep diving submarines must possess a level of strength adequate to resist high hydrostatic loads, and to accommodate certain levels of underwater explosive loading, perhaps after a period of service during which there may have been progressive accumulation of fatigue damage at critical positions. As a result, design and construction is supported by type tests on simulated structures under exaggerated loading. While such tests are invaluable in providing confidence in design, they are expensive and unsuitable for quality control of steel production and the actual fabrication of large structures on site by welding processes. It has thus become necessary for simple tests to be carried out as far as possible under simulated loading conditions, and on material which has been fabricated (*e.g.*, by welding) and subjected to other changes likely to occur during service (strain ageing, strain hardening and fatigue). Some such special tests which have been evolved to establish the temperature/energy absorption characteristics under simulated operational loading, are shown in Fig. 8, and the variations in the transition temperature obtained arise from the differences in notch acuity and the mode and rate of loading employed[6].

Generally speaking, the effect of strain rate on the strength of metals is to raise the yield and ultimate tensile strength and to reduce the ductility, but the situation for steel compositions showing ductile and brittle fracture phenomena is more complicated. The general effect of increasing Charpy impact velocity on a given steel composition is to raise the transition temperature in the way shown in Fig. 9, and to reduce the energy of absorption capacity (and hence reduce resistance to shock) in the way demonstrated three dimensionally in Fig. 10. The results given are indicative of how the rate at which stress is applied to the advancing crack front influences the mode of fracture. Instances occur however, where the shock wave can be interrupted by a series of arrests at the fracture surface. The fracture illustrated in Fig. 11 is an excellent example of this and shows that under certain conditions, although the steel is capable of arresting a running brittle crack, the rate at which energy is fed to the tip promotes fresh cracking from a sequence of ductile steps. Thus, by fixing arbitrary operational limits of shock, and by acquiring data on the response of simple test pieces to temperature and rate of loading, it is now becoming possible to establish a closer link between steel and welding development and design.

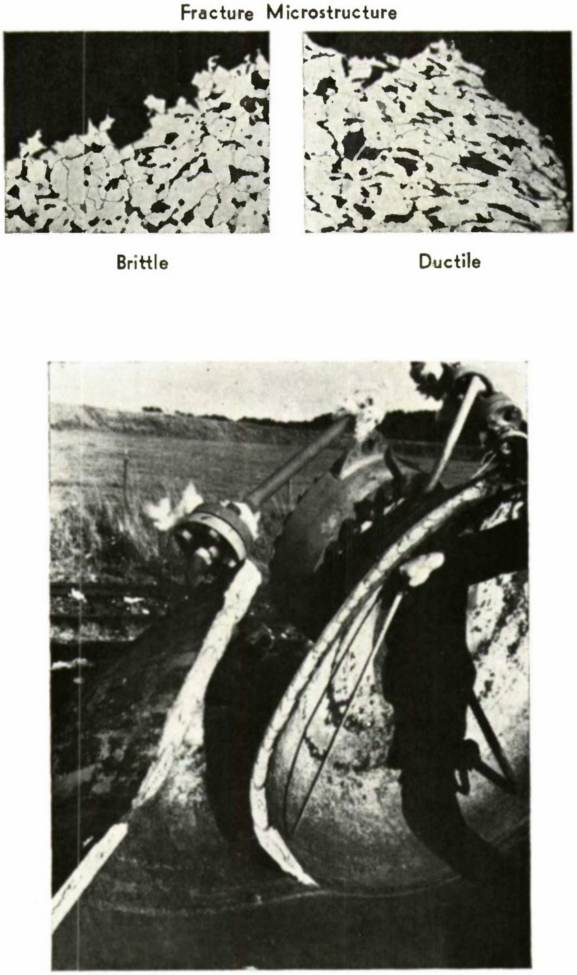


FIG. 11. Fracture Surface Showing Brittle Crack Growth Associated with Ductile Steps. Inserts show the typical Ductile and Brittle Fracture Paths.

FIG. 12. Fracture of a Steel Plate Showing Propagation of a Brittle Fracture from a Fatigue Crack.

Design Considerations

Where the normal ductility of mild and low alloy steels provides a margin of safety in design, the main consideration is to ensure that the inherent transition temperature of the structure is known, and not passed under operational conditions which fortunately for submarine hulls has a minimum level around 0°C. While choice of material is the first consideration, design and fabrication to avoid long crack paths without crack arrests, and vigorous non-destructive testing during construction is essential. Knowledge of the location and magnitude of residual stress concentrations in weldments, and means for their removal is essential. Methods for achieving this include annealing or re-distribution of local stress by mechanical or mild explosive overloading. Local mechanical peening to replace tensile by compressive stress, is another valuable technique for minimising the risk of crack initiation at sensitive points, or for deflecting potential crack growth by fatigue processes, away from such areas.

Although no direct correlation between fatigue damage and brittle crack propagation exists, the progression of one form to the other is a distinct possibility, as may be seen from Fig. 12, particularly as limited life structures may employ cyclic stresses approaching the yield point of the material.

Some idea of the relationship between the strength of steel and resistance to fatigue is given in Fig. 13 from which it may be seen that a point of limiting return is reached at an ultimate tensile strength level of 70 t.s.i. The possibility of progressive micro-damage just beyond the tip of an advancing crack giving rise to stepped brittle fracture as a fatigue crack progression process under local yield point loading conditions, cannot be discounted.

Over the past decade an increasing awareness of the criticality of crack length in relation to sudden catastrophic failure has been realised. It is inevitable that most structures will contain some flaws in the shape of inclusions and micro- or

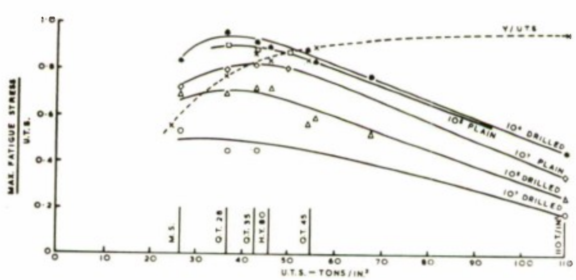


FIG. 13. The Relationship Between Ultimate Tensile Strength and Fatigue Strength of Steels.

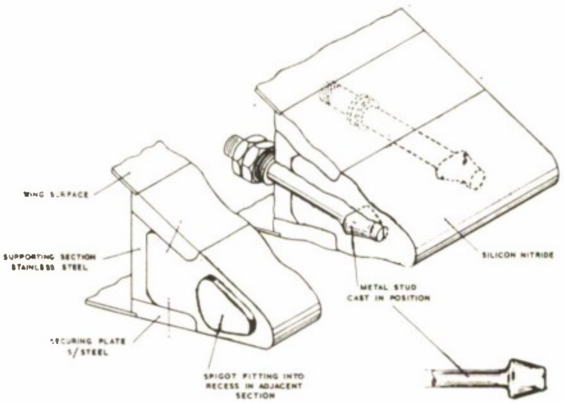


FIG. 14. Example of the Strategic Use of a Brittle Material.

macro-cracks. Where these are non-propagating, or slow to propagate as a result of re-distribution of working stresses at their tips by inherent ductility, they do not constitute a hazard. However, if as a result of steel condition or fatigue damage, such flaws extend under working loads, a condition of stress instability may be reached where the crack will suddenly develop from a slow to a fast catastrophic fracture. The relationship between flaw size and rate of crack propagation is perhaps illustrated most dramatically in glass, where actual strength is only a small proportion of the possible strength due to small microscopic flaws.

However, by developing suitable design criteria[7], [8], in particular to avoid high tensile loading, particularly as local stress concentrations, in favour of compression and shear loading, it is possible to use safely high strength, less tough materials (or normally tough materials below their transition temperature), for certain applications. In such cases long crack paths are to be avoided so that employment at strategic positions rather than for complete rigid structures is to be advocated.

Furthermore, as safety factors based on imprecise stress analysis cannot be safeguarded in non-ductile materials as a result of the local rounding off of stress concentrations by yielding, it is essential that safety factors should be based on the results of destructive tests on actual components stressed under exaggerated service loading conditions. Fig. 14 is an example of the application of a brittle material, in this case a ceramic, to overcome extreme conditions of frictional heating on the leading edges of a high speed air frame.

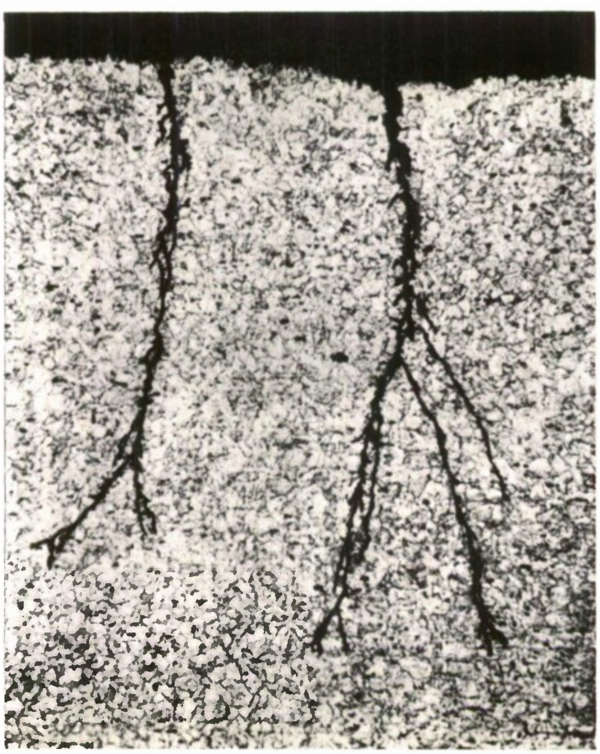


FIG. 15. Typical Stress Corrosion Cracking in Stainless Steel.

Effect Of Environment

The environment in contact with steel surfaces can in certain circumstances seriously affect the metallurgical integrity of a structure by generating or extending surface flaws, or by accelerating crack propagation directly by selective solution, or indirectly by atomic hydrogen penetration with consequent embrittlement. While the effect is not usually pronounced in mild and low alloy steel structures it is very significant to the use of high strength alloy compositions. As an example of this, the proneness of stainless steels to high selective stress corrosion cracking shown in Fig. 15 constitutes an important hazard to the circuitry of pressurized water nuclear reactors in true submarines. While careful selection of structural material and associated fabrication processes can do much to ensure safety against this form of deterioration, a greater assurance from trouble can be achieved by control of the corrosive environment (in this case high pressure high temperature water containing only traces of impurity elements) by the employment of inhibitors.

Another aspect of environment which gives rise to embrittlement and catastrophic failure is the effect of neutron irradiation on the transition temperatures of mild and low alloy steels selected for pressurized water nuclear reactor pressure vessels[9]. In the choice of material for such an application it is necessary to select the steel and associated fabrication processes to give a low, initial transition temperature, so that during the life of the plant the total neutron exposure of the

containment vessel does not result in a rise in transition temperature to a level above the working temperature. Fortunately much of the damage caused by lattice disturbances as a result of collisions with fast moving particles in the manner shown in Fig. 16, is removed by immediate re-ordering, and in some cases the working temperature of the reactor enhances the recovery process.

Embrittlement of steel will also occur if atomic hydrogen is permitted to permeate through the structure. The source of such hydrogen can be from industrial processes such as pickling and welding, and from corrosion processes during service life. Fortunately combination to molecular hydrogen usually occurs on the surface, thus prohibiting entry of atomic hydrogen into the structure. Where hydrogen penetration occurs, embrittlement can be temporary, and ductility restored as hydrogen diffuses from the structure at a rate which depends upon time, and the process can be accelerated by increasing the temperature. The effect of hydrogen in promoting the formation of cracking in certain hardened martensitic zones has already been mentioned in connection with welding. However, the combination of atomic hydrogen to molecular hydrogen inside the structure can occur at inclusions or discontinuities, where it may be stored and released in a harmful way to promote brittleness when residual or applied stresses promote disturbances in the neighbourhood.

Extreme environmental conditions is a relative term, and so the equipment which normally operates efficiently may cease to do so if subject to unusual influences. Typical of this is the rapid erosion of components such as gas turbine compressors and helicopter tail rotors when subjected to dust. Similarly injection of salt spray into marine gas turbines can cause rapid deterioration of high temperature alloy turbine blades by thinning and cracking.

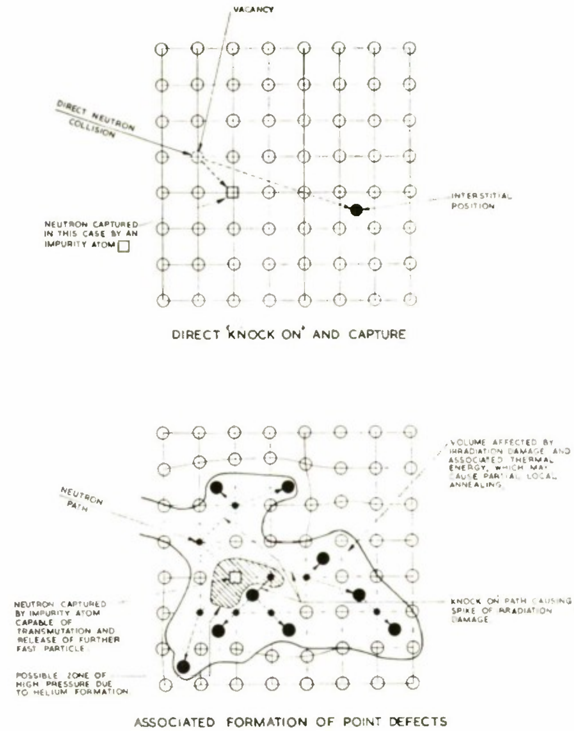


FIG. 16. Representation of the Mechanism of Irradiation Damage in Steels.

Future Research and Development

The above gives some idea of the problems which have to be faced in the design and construction of steel equipment for prosecuting warfare under extreme conditions. Whilst in the past, engineering development and production have been, and still are, based on empirical tests, the increased load-bearing requirement dictated by extreme conditions is demanding a greater knowledge of steel constitution in relation to the various fracture processes that have been described. Dislocation and fracture mechanics theories have been considerably developed over the past two decades, and have contributed much to the meaning and performance of constructional materials, in particular steel, but the gap between basic knowledge and engineering application still remains to be closed. Improvement in communication between the requirements of the design on the one hand, and the performance of the material on the other from the results of more meaningful tests would constitute a first step. One area in which progress is being made is in the development of sensitive monitoring devices to locate and measure the rate of progression of flaws, or to detect any reduced resistance of a particular area to brittle crack propagation during service life.

With regard to future steel development, the indications are that simultaneous increases in strength, toughness, and weldability, may perhaps be achieved by a change in existing steel constitution to fine grained irons, stiffened with fine dispersions of intermetallic phases. Such new material is in an early stage of development, and its availability will depend not only on favourable progress in research and development, but in the partial recapitalization of the steel industry.

So much for the immediate future, but what will be the position with regard to brittle fracture in two or three decades ahead ? Already, synthesized structural materials with high specific strength and

other interesting properties are beginning to challenge steel for advanced application. Included in these are graphite fibre-reinforced plastics and hard, strong, but brittle inorganic non-metallic compounds, bringing new challenges to design and production, amongst which, the possibilities of brittle fracture will be a major factor to be considered.

Acknowledgements

The literature on brittle fracture is enormous and this reflects the vast amount of work which has been devoted to the subject over the last three decades. It was therefore difficult to present the science in a new light, but the explanations and opinions expressed in the foregoing have been distilled from work proceeding within M.O.D.(N) establishments particularly the Naval Construction Research Establishment and the Admiralty Materials Laboratory, and by contractors and advisers concerned with the problem of brittle fracture. Particular mention must be made of the valuable work of the Navy Department Advisory Committee on Structural Steel, formerly known as the Admiralty Advisory Committee on Structural Steel. The author gratefully acknowledges the assistance and data given to him by his colleagues at these centres and within these bodies.

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(9) "Steels for Reactor Pressure Circuits". Special Report No. 69, The Iron and Steel Institute, 1961. Printed by Percy Lund, Humphries & Co. Ltd., London, 1961.

NAVAL AIRCRAFT MATERIALS LABORATORY

The extension to the Naval Aircraft Materials Laboratory was formally opened by Director General Aircraft (Naval), Rear Admiral Holt, B.Sc., F.I.E.E., on 26th October, 1967. The extension had been completed earlier in the year but was not fully functional until modifications to and refurbishing of the original laboratory building was finished.

Visitors to the opening ceremony included Rear Admiral Illingworth, Rear Admiral Engineering to the Flag Officer Naval Air Command, Dr. R. H. Purcell, C.R.N.S.S., Mr. N. L. Parr, D.M.R.(N.), and senior Naval officers of Commonwealth Navies and administrative authorities and establishments with whom the laboratory is closely concerned in its work.

Rear Admiral Holt was introduced by the Superintendent, R.N.A.Y. Fleetlands, Captain K. Hickson, R.N. The simple opening ceremony took the form of the unveiling of a plaque in the main entrance hall. This was followed by an informal conversazione and a tour of the establishment. Current activities and available facilities were demonstrated, illustrating the service given by N.A.M.L. to the Fleet Air Arm in the field of chemical, metallurgical and general scientific investigation as applied to aircraft engineering.

It is anticipated that this service can be rendered even more efficiently now that the laboratory is housed under one roof.

The photograph shows Admiral Holt performing the opening ceremony, accompanied by Mr. E. J. Hammersley, Officer in Charge, N.A.M.L., and Captain Hickson.

RETIREMENT

L. SAMPHIER, A.C.G.I., D.I.C., C.Eng., M.I.E.E., R.N.S.S.

A.U.W.E. and the Portland area lost one of its oldest inhabitants when Mr. Len Samphier, Principal Scientific Officer, retired in August after 40 years of Crown Service spent almost entirely in underwater warfare equipment design and development.

His service started as an apprentice in Portsmouth Dockyard and after completing this he studied at City and Guilds College (London University) subsequently taking up a teaching post for a year. He had by now decided that he would like to work in close collaboration with the Royal Navy and in 1927 joined H.M.S. OSPREY at Portland as a Junior Technical Officer.

In the years before the Second World War he worked at a wide variety of projects including the magnetic detection of submarines by indicator loops for harbour defence. He remembers being the first to use a CRO in H.M.S. OSPREY when all that was provided was the tube and mounting base and one had to design and construct timebases and amplifiers on copper-sheeted plywood.

With the evacuation of H.M.S. OSPREY'S scientific staff to Fairlie in 1940 when H.M.A/S E.E. was formed, Mr. Samphier developed several towed and static sonar targets and also worked on equipment for the detection of sneak craft—the chariots and one-man submarines. He was a member of the Admiralty team which planned the harbour defence systems for the major continental ports before the invasion of France in June 1944.

When H.M.A/S E.E. returned to Portland after the war under its new title of U.D.E., Mr. Samphier did a considerable amount of work on the reduction of propeller noise by air emission which culminated in the adoption of the Agouti system for Fleet use. In 1950 he was promoted to Principal Scientific Officer and for the next four years he was employed on sonar dome design for surface ships and submarines. Then in 1955 came his only period away from underwater warfare and with the formation of the Admiralty Gunnery Establishment at Southwell, Mr. Samphier was transferred " up the hill " to work on *Sea Slug*.

When the Director General Weapons Department came into being in 1959 and A.G.E. became A.U.W.E. (South), he returned to the underwater field and since that time until his retirement he has been employed on mine countermeasure work and equipment for use by the Navy's Clearance Divers.

For many years Mr. Samphier was Chairman of the U.D.E. Branch of the Staff Association for 'S', 'E' and Assistant grades and was the H.Q. promotion scrutineer before four chiefs of the R.N.S.S.

He has always taken the keenest practical interest in amateur theatricals and in 1962 he wrote and produced an amusing and highly illuminating playlet for the T.A.S. Conference at Portsmouth Guildhall which illustrated the vicissitudes and devious channels through which a project must pass before the Navy receives its hardware.

Mr. Samphier plans to spend his retirement in Dorset and at the moment finds his time fully occupied in watching the progress of his house now being built at Sutton Poyntz and making plans for the work to come on the garden.

All his old colleagues at A.U.W.E. wish him a long and happy retirement.

Notes and News

Admiralty Compass Observatory

The Jubilee year of A.C.O. has been celebrated by a garden party, which was an auspicious occasion even though inclement weather restricted much of the party to a garden view from inside. Local civic authorities honouring the celebrations were the Mayors and Mayoresses of Slough and Windsor and the Chairman of the Eton Rural District Council and his wife. Naval guests included the late Director, Capt. C. J. Wynne Edwards, D.S.C. and his Deputy, Cdr. A. V. Thomas; the Director of Navigation, Capt, J. S. Le Blanc Smith and the Captain of H.M.S. *Dryad*, Capt. M. S. Ollivant, M.B.E., D.S.C. Senior guests in the scientific field included Dr. R. H. Purcell, C.B., C.R.N.S.S. and Mr. A. F. Wilkins, Deputy Director of A.C.O's neighbouring Radio and Space Research Station.

Dr. W. W. Jackson, lately Deputy Director of Naval Physical Research in M.O.D. Headquarters, has joined the observatory as Deputy Chief Scientist.

Mr. J. Rigby, a member of the Laboratory staff who was formerly Deputy Mayor of Slough, has been elected an Alderman of the Borough.

Mr. J. L. Howard and Mr. E. C. Chaston visited the U.S.A. and Canada during July to discuss magnetic anomaly detection (MAD) equipment and associated compensation devices for the *Nimrod* aircraft (HS 801) project. Consultations were held with Grumman Aircraft, N.A.D.C. Johnsville, N.A.S.C. Washington and Emerson Electric, St. Louis, in the U.S.A. as well as with N.A.E. Ottawa and C.A.E. Montreal in Canada.

The installation of U.P.T.E. (Ultra Precision Test Equipment for Gyros) at A.C.O. has now been completed. Prior to its installation, Dr. J. Preston and Mr. J. Norton visited the United States, where the equipment was designed and built by Nortronics, Boston, to study its performance and use. Subsequently, American engineers visited the observatory to assist in its installation. This equipment will give A.C.O. a gyro test capability of the highest precision outside the U.S.A. and equalled only by two American organisations. It is hoped later to include an article on this equipment in a forthcoming issue of *J.R.N.S.S.*

Mr. H. J. Elwertowski has visited the United States on two occasions during recent months. His tours have included discussions with U.S. Government officials, visits to government laboratories and firms in connection with navigational and allied equipment as well as attendance at meetings of the Office of Naval Research Gas Bearing Coordinating Committee. At the October meeting of this Group in Chicago, he was accompanied by Mr. A. G. Patterson, who gave a review of British progress in the gas bearing field. Mr. Patterson also visited Massachusetts Institute of Technology and Lear Siegler Inc. of Grand Rapids, Michigan, in connection with gas bearing projects and attended the annual joint conference at Chicago of the American Societies of Mechanical and Lubrication Engineers.

Mr. C. K. Gulland visited Teledyne Systems Corp., Culver City, California, U.S.A. during October to attend demonstrations of miniature inertial navigation equipments.

Mr. J. L. Howard represented A.C.O. at the International Standards Organisation meeting held in Paris in October in connection with the standardisation of ship's compasses and binnacles.

On November 10th, A.C.O. was visited by Mr. Roy Mason, Minister of Defence (Equipment), who was given a concise account of the work in progress when he toured part of the Establishment.

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Admiralty Experiment Works

It has recently been announced that the Royal Corps of Naval Constructors is to transfer its training from Royal Naval College, Greenwich, to University College, London.

In order to provide facilities for hydrodynamic research, which is regarded as an essential part of the training of the students, a small research group from U.C.L. will take up permanent residence in A.E.W. this year.

Sir Alfred Sims, K.C.B. (D.G. Ships) introduced the Summer School on Directional Stability and Control of Ships which from September 26th-October 6th was held at N.P.L. (Ship Division) and A.E.W., and remarked that W. E. Froude, the father of tank experiment, had been somewhat in error in predicting that a two year programme would suffice to investigate all problems of ship resistance, propulsion, stability and control. New designs and new requirements of ships bring new problems, and Britain as a maritime nation could not afford to lag in the marine sciences. Sir Alfred thanked Professor R. E. D. Bishop for his initiative in organising the course and hoped that other courses would follow. Later Sir Alfred attended the course in session at A.E.W.

The course was oversubscribed. Thirty-two participants attended, from Industry, Universities, the Services and Government and Private Establishments, and including visitors from Italy and Germany. Judging by the lively discussions which followed some of the lectures, demonstrations and tutorials, all departed wiser than they came, including the lecturers.

While the theory for the treatment of stability and control is well established, and computing power now exists, the necessary supporting test facilities (admittedly expensive) are barely adequate in the U.K. The " poor man's " alternative tests appear to be equally expensive and produce indices and graphs of limited value.

The Course Dinner was held in the Guildhall, Portsmouth by kind invitation of Vosper Limited. Commander Peter du Cane (Deputy Chairman) in welcoming the course referred to the need for advanced training in marine sciences. The guests included the Mayor Conners (Lord Mayor of Portsmouth), Councillor Cooley (Mayor of Gosport). The Very Reverend Porter Goff (Provost of Portsmouth Cathedral) and Sir Alfred Sims, K.C.B.

The lecturing staff were Professor R. E. D. Bishop, Dr. A. G. Parkinson and Dr. B. Massey (University College, London); Mr. G. Goodrich and Dr. G. Lewison (N.P.L.); Mr. R. Akhurst and Mr. T. B. Booth (A.E.W.); Mr. D. Clarke (B.S.R.A.); Mr. M. Barret (Hovercraft Development Ltd.).

At the conclusion of the course Mr. A. Vosper (Superintendent A.E.W.) presented a king sized chess bishop in polished redwood to Professor R. E. D. Bishop.

Vice Admiral Sir H. Law, K.C.B. (Controller, Royal Navy), Admiral F. Rassai (C. in C., Iranian Navy), and Mr. K. M. Heggstad (Chief Naval Architect, Royal Norwegian Navy) visitel A.E.W. during the summer. Mr. W. Cummins (Head of the Hydromechanics Division, N.S.R.D.C. (formerly David Taylor Model Basin), visited the establishment accompanied by five members of his staff.

Mr. A. Vosper accompanied by Mr. P. Lover attended the Symposium on Cavitation in Trondheim, Norway. Later the Superintendent visited the Canadian Naval Forces H.Q. in Ottawa, the Stevens Institute, New York and the N.S.R.D.C.

Mr. T. Booth was the U.K. " boatrider " for the DASO trials of the last U.S.N. Polaris submarine, SSBN 659 " Will Rogers," at Port Canaveral. (These trials were conducted by Commander P. Cave, R.N., a unique occasion). Mr. Booth then visited the new U.S.N. AUTEC tracking range on Andros Island.

Mr. O'Dell was invited to deliver a lecture at the Stevens Institute, New Jersey and also visited N.R.C. Ottawa, N.S.R.D.C. Washington and San Diego.

Mr. G. Cox has now joined the brain drain to join the staff of N.S.R.D.C., and Mr. A. Skeels has retired after over 40 years' service with the Royal Navy and the R.N.S.S.

Admiralty Materials Laboratory

The second Discussion of Fuel Cells was held at A.M.L. on 26th and 27th October. Twelve short papers on various aspects of fuel cell research and technology were presented and these formed the basis for lively discussions. Over seventy people attended, including representatives of industry and universities, as well as Service departments. A report of this discussion is to appear in *J.R.N.S.S.* (A report on the first discussion appeared in *J.R.N.S.S.* **21** (1966) 268).

Dr. C. A. Parker attended by invitation the Nobel symposium on " Fast Reactions and Primary Processes in Chemical Kinetics " held in Stockholm, 27th August to 2nd September, 1967, where he presented papers on delayed fluorescence and energy transfer.

Mr. J. F. G. Condé attended the International Power Conference at Lausanne, Switzerland, 10th to 13th October, 1967.

Dr. K. H. Wheatley visited the U.S. during October, 1967, for discussions on air purification topics and visited U.S. government establishments and other agencies working in this field.

Mr. N. I. Hendey attended the symposium on Micropaleontology of Marine Bottom Deposits held at Cambridge 11th to 13th September, 1967, by the Scientific Committee of Oceanic Research of UNESCO, at which he presented a paper entitled " The Impact of the Electron Microscope on the Systematic Classification of Diatoms ".

A paper entitled " Theoretical and Pragmatic Approaches to the Development of Design Criteria for Brittle Materials " by N. L. Parr, D. J. Godfrey, and K. W. Mitchell, was presented to the AGARD symposium on Brittle Material Design held in London, 4th to 6th September, 1967.

The following papers have been published:—

" Delayed Fluorescence of Anthracene and Some Substituted Anthracenes " by C. A. Parker and Thelma A. Joyce, *Chem. Commun.* (1967), 744.

" Some Recent Developments in Non-Destructive Testing " by D. Birchon, D. E. Bromley, and P. M. Wingfield, *The Engineer*, **224** (1967), 590.

Mr. Cyril Kenyon, Senior Experimental Officer, retired at his own request on 31st August, 1967, after 29 years' service.

Central Dockyard Laboratory

Mr. D. R. Houghton, who has recently been appointed chairman of the Sub-Group on Biology of the Permanent International Committee for Research on the Preservation of Materials in the Marine Environment, attended the Second General Assembly of the Committee at La Rochelle from 3rd-6th October, 1967.

Mr. J. Smith attended the Fifth Meeting of the International Organisation for Standardisation (ISO/TC39/SC9), in Paris on 24th-26th October 1967, and was chairman at the meetings of the working parties on "Artificial Weathering " and " Humidity Testing ".

Mr. J. N. Bradley and Mr. G. Newcombe attended the Autumn Meeting of the Institute of Welding on 31st October 1967, and presented a paper entitled " Review of Non-Ferrous Alloy Weldments for Naval Service ".

Naval Construction Research Establishment

On 12th October N.C.R.E. was honoured by a visit from H.R.H. Duke of Edinburgh, accompanied by Flag Officer Scotland and Admiral Superintendent, Rosyth Dockyard. H.R.H. toured the South Arm of N.C.R.E. and was briefed on research projects by Mr. J. R. F. Moss, Superintendent, Dr. J. L. King, Chief Scientist, and senior R.N.S.S. staff. See page 54.

Earlier, in August, the Controller of the Navy, Vice Admiral Sir Horace Law, K.C.B., visited N.C.R.E. to discuss the research and development programme with Chief Scientist and Heads of Divisions.

Chief Scientist, accompanied by Messrs. S. B. Kendrick, A. N. Hicks and A. M. MacIntosh, visited N.S.R.D.C., Washington, in October for formal discussions on the co-operation research programme between the two establishments. Dr. King and Mr. MacIntosh also attended the Symposium on Shock and Vibration at Orlando, Florida, where Mr. MacIntosh also presented a paper entitled " Present Work on Shock at N.C.R.E."

Mr. F. Weinberger, Head of the Shock Division at N.S.R.D.C., Washington, visited N.C.R.E. for a three-month period recently under the personal exchange programme.

Mr. N. J. Gibb, Senior Scientific Assistant, retired on 24th October after 23 years' service in the Navy Department.

Book Reviews

Torsional Vibration. By Professor W. A. Tuplin. Pp. xii + 193. London; Sir Isaac Pitman & Sons Ltd. 1966. Price 25s.

This applied mechanics monograph deals exclusively with the torsional vibration of shaft systems and their usual appendages of flywheels, cranks, gearwheels, *etc.* The main theme of the book is the simplicity of evaluating the resonant frequencies of multi-mass straight line systems by the Crossley-Germen method, the whole process being reduced to simple arithmetic and a tabulation of results. The origins of vibratory torque in shafts are discussed under chapters on critical speeds and forced vibration, and the mode shapes of the shaft at these critical frequencies are determined.

Methods of reducing the vibratory amplitude by applying vibration dampers or absorbers to the shaft are described. Here absorber is used in the sense of absorbing torque, normally by resonant reaction, rather than absorbing energy, which is of course the function of the vibration damper.

The reductions in magnification at resonance obtained by such devices are calculated, and the effects of non-linearity in the torque-twist relation investigated. Geared systems on heavy shafts are also considered as well as the effect of rotational impact. The main text ends by describing a few instruments used in the measurement of torsional vibration. This is followed by eight appendices giving additional formulae and their derivation, a note on harmonic analysis, and a few of the physical properties of metals and rubber. Throughout the whole book emphasis is placed on worked numerical examples.

This book will be of benefit mainly to practising mechanical engineers who have simple torsional vibration problems to solve and who cannot easily obtain access to a computer, or perhaps to mechanical engineering students. However, as a student's introduction to this subject the book leaves very much to be desired. The author states that his intention is to reduce the use of differential equations to a minimum and unfortunately in doing so some clarity is lost, and a few formulae have to be taken on trust.

A small but sufficient bibliography and references are found at the end of the volume.

J. M. Donaldson

Vibration Theory and Applications. By W. T. Thomson. Pp. xi + 384. London; Allen & Unwin Ltd., 1966. Price 42s.

The topic of vibration must cover a large part of present day physics and quite a bit of engineering, but the subject matter of this book is not quite so far ranging as that. It deals with vibration in mechanical systems, occasionally deliberately produced, more often an undesired complication in design. The text handles the argument in a general mathematical way while the practical application is largely developed by worked examples and problems associated with each chapter, which refer freely to such items of the engineer's repertoire as shafts, flywheels, and motor car suspensions. The exposition necessarily depends on differential equations, but the style is very clear, there is a profusion of excellent diagrams, and an undergraduate student should not find it too difficult.

The development proceeds naturally from the simplest case of an undamped motion to more advanced topics with chapters on shock excitation, Laplace transforms, and random variables. A student working conscientiously through it would end up knowing quite a lot about mechanical vibrations. As particular merits there is a full discussion of resonance illustrated by useful graphs, and tables of the normal modes of a beam as an appendix.

On the debit side, phenomena of more than two degrees of freedom, and propagation of vibration receive only restricted discussion. Sound is in no way a topic of the book and figures neither in the table of contents nor the index. The close analogy between electrical and mechanical vibrations, which is often a powerful stimulus to understanding is not explicitly discussed. Although it is no doubt implicit in the treatment of analogue computer techniques, it is unlikely many students will realize this.

The need to produce a work of a reasonable size and within the understanding of its prospective readers no doubt justifies the author's particular choice of topics. Some more general features induce reservations in recommending it. On the mathematical side the development has an arbitrary air about it, and at the same time there seems little awareness of the need, or even the existence of experimental methods. The approach is to provide formulae for design calculation in relation to the drawing board. Perhaps this is only to say this is a design engineer's book, and not a physicist's, or mathematician's. It is an excellent and attractive treatment, but to form a full understanding of the phenomena of mechanical vibration would require a more flexible approach, and some supplementation by a teacher, or from other books.

D. E. Bromley

High Intensity Ultrasonics—Industrial Applications. By B. Brown and J. E. Goodman. Pp. viii + 235. London; Iliffe Books Limited, 1965. Price 55s.

The applications of low intensity ultrasonics for flaw detection, control and measurement have been reasonably well covered in the earlier literature of the subject but the rapidly growing field of high intensity applications has been neglected to a large extent. In this book, which is claimed to be the first comprehensive survey of the industrial applications of high intensity ultrasonics, the authors appear to have made a successful attempt to fill such a gap.

Fundamental principles involved in the propagation, absorption, and measurement of ultrasonics are dealt with in the introductory chapter. The treatment of the theory in this chapter and throughout the book is sufficiently mathematical to make it valuable to the technologist or engineer. It is followed by an important chapter, occupying approximately a tenth of the book, giving a thorough treatment of cavitation theory and experimental results. The authors at this stage point to the need for more research especially on the variation of cavitation intensity with frequency.

The next two chapters deal with the production of ultrasonics by mechanical generators (whistles and sirens) and the design aspects of magneto-strictive and piezo-electric transducers. Power supplies, transducer coupling methods and velocity transformers are also

covered in detail. Wherever it is appropriate design data is supplied and abundant references are provided throughout the text and listed at the end of each chapter.

The second section of the book is devoted to the practical applications of high intensity ultrasonic energy and these are divided by the authors into ultrasonic cleaning, ultrasonic homogenization, metallurgical effects and chemical and biological effects. The chapter on ultrasonic cleaning describes modern techniques and equipment and includes tables, the first of which compares the characteristics of transducers, and the second which shows the results of various practical cleaning tests employing a variety of cleaning media.

The large number of commercial applications for ultrasonic homogenization justifies a complete chapter on the subject and this includes a detailed table listing recommended methods and machines for the manufacture of an extensive range of products ranging from Ketchup to antibiotic dispersions.

Metallurgical applications are given a complete chapter with information on the soldering of aluminium, ultrasonic drilling, welding, fatigue testing and the irradiation of molten metals for grain refinement, dispersive effects and de-gassing. The applications for ultrasonic irradiation to chemistry and biology are considered in the final chapter. The many chemical or physico-chemical effects discussed include the initiation of reactions, precipitation, crystallisation, de-gassing, and atomisation, and finally the biological phenomena of cell content extraction, bacteriological action and mutation.

One surprising omission is a full discussion on health hazards. Indeed this subject receives scant mention, the authors merely stating that the ability of their colleagues to appreciate good music is apparently unaffected after long exposure to high intensity ultrasonics. Although much work remains to be done in this field, it is known that ultrasonic equipment using continuous waves at powers exceeding a few milliwatts per cm^2 can be considered to be dangerous due to the effect on hearing in the case of airborne noise, and may cause irreversible tissue or blood cell changes in the case of direct contact of the body with a transducer or cavitating liquid.

Apart from the above minor criticism, the book clearly embodies a great deal of invaluable experience and the authors have succeeded in collating a large amount of information much of which has not hitherto been available.

S. Bagley

Ultrasonic Engineering. By J. R. Frederick. Pp. xii + 379. New York, London, Sydney; John Wiley & Sons Inc., 1965. Price 113s.

Although much information is available on the individual specialized areas of the ultrasonics field, a book supplying a comprehensive introduction to the whole subject is a rarity and as such is a worthwhile contribution to the literature. It is directed at the engineering profession and is intended as a general introduction to the industrial, laboratory, and medical uses of ultrasonics. Wherever appropriate a description of the underlying fundamental principles involved in each application is included.

In his introductory chapter the author discusses the meaning of the term "ultrasonic engineering," takes a brief look at the history, the range of applications, the engineering and the future of ultrasonics with a hint at the new piezo-electrical transducer materials which are expected to transform ultrasonic power generation. Basic principles of ultrasonics are then discussed in the following chapter with a brief reference to the non-linear behaviour of high amplitude sound waves. A knowledge of advanced mathematics is not essential for an understanding of this section as the treatment is simple and practical and does not present the subject in any great depth.

After dealing with the basic elements for the application of ultrasonics to industrial processing, the author includes a valuable section on health hazards. Possible effects on health include hearing loss, physiological effects such as nausea, fatigue, pain, blood changes and the irreversible destruction of body tissue by mechanical effects or the production of heat through direct contact with transducers. It is evident that much work remains to be done on this subject and effective standards are lacking, but one useful statement made is that any equipment using continuous waves and generating more than a few milliwatts per cm^2 is a possible danger to health.

In the following chapter, the author deals with the design aspects of various types of ultrasonic transducers applicable to industrial processing. Recent data on the various piezo-electric and magneto-strictive transducer materials are included in this section and in addition, information on the various types of ultrasonic generators.

The various factors affecting cavitation intensity are discussed in the next section and this is followed by detailed descriptions of a wide range of ultrasonic applications to industrial processing. As might be expected, the important processes involving cavitation, *e.g.* cleaning, emulsification, homogenization and de-gassing of liquids are treated at length. Several ultrasonic machining and some metallurgical applications are discussed in detail. The uses of ultrasonics in industry are continually increasing and examples as divergent as the production of aerosols and the relief of residual stresses in metals are described.

Measurement applications are discussed in detail in the following chapter and these include velocity of liquids, displacement, vibration, density, viscosity, thickness, hardness of metals, and the temperature of hot gases and plasmas. The control techniques for liquid level sensing, television remote control, counting, and sorting are described in the same chapter.

In a book written by a colleague of Firestone, the inventor of the pulse-echo system in America, it is not surprising that a significant part of the work (approximately one sixth of the content) is devoted to the non-destructive testing applications of ultrasonics. The treatment of this material is lucid, fairly comprehensive and forms an excellent introduction to the subject.

Biological applications are covered in a short chapter which includes a table describing the effects of ultrasonic radiation on various biological materials ranging from viruses to skin tissue.

Developments in the application of ultrasonics to the medical field have provided sufficient material for a complete chapter on this subject. Two main categories of the applications are discussed; firstly, those using minute intensities such as in pulse-echo diagnostic methods and, secondly, those which employ a finite amount of energy for the treatment of disease. The diagnostic methods use similar principles to those employed in the non-destructive testing of metals but the author presents sufficient data on the velocities of ultrasound and sound absorption coefficients for various human tissues to be of special interest to the medical profession.

In a book attempting to provide a comprehensive coverage of a subject as wide as ultrasonics, some omissions are inevitable and the author has deliberately left out the underwater applications of sonar, and ultrasonic signalling. Furthermore some applications, *e.g.*

ultrasonic guidance for the blind and the ultrasonic hardness measuring instrument have progressed since the book was written from the development stage to actual manufacture. These comments of course, cannot be held as criticism of the book but as signs of the rapid expansion of the subject.

Numerous references are quoted in footnotes throughout the text and the book is very well produced with many excellent figures and line diagrams. It is concluded with three useful appendices, the first of which is a short guide to the ultrasonic literature, the second a table of ultrasound velocities, densities and characteristic impedances of various materials and the third is a table listing cleaning fluids, bath temperatures, and immersion times for various cleaning applications.

Unfortunately the text contains a number of irritating minor errors which should have been eliminated at the proof reading stage. The relatively high price of the book will undoubtedly deter the casual reader but it is considered to be a useful addition to the library of any engineer or technologist involved in almost any branch of ultrasonic applications.

S. Bagley

Application of Fracture Toughness Parameters to Structural Metals. Edited by H. D. Greenberg. Pp. x + 406. New York, London, Paris; Gordon & Breach, Science Publishers (Distributed by Blackie & Son Ltd.), 1966. Price 200s.

This volume comprises the ten papers which were presented at the 1964 Fall Meeting of the Metallurgical Society of A.I.M.E. in Philadelphia sponsored by the Structural Materials Technical Committee of the Institute of Metals Division. For this, the latest of four symposia in the programme of the Committee, the authors, all American, were drawn equally from universities, the electrical generating industry, government research, aero space constructors and steel manufacturers.

The first two papers were specifically intended to review the theory and background of fracture mechanics and the latest test methods for measuring fracture toughness. In the first, the author analyses tensile fracture and develops models for the initiation of cracks. He then develops in turn the Griffith relationship for crack growth based on energy criteria and the stress field conditions for failure based on a crude application of Hooke's law and demonstrates the equivalence of these two approaches. The departures from ideality, the interaction of the properties of the materials with geometrical and size effects are discussed with relation to the macroscopic appearance of fractures obtained in practice. The second paper is largely concerned with a comparison of the two principal concepts for evaluating brittle fracture behaviour, namely the ductile-to-brittle transition temperature approach and that based on sharp crack fracture mechanics. The authors review a number of test procedures and analyses currently used to assess fracture resistance and discuss the factors which determine the test conditions and in turn affect the application of the results to material selection and design.

The three papers of the next group describe practical applications of various fracture-safe principles to specific structural components. The first analyses the failures of some ultra-high strength steel rocket motor cases in terms of the concept of critical thickness and demonstrates that this semi-qualitative fracture mechanics approach can be used to ensure satisfactory design. As if to keep the option open, the next paper achieves the same practical objective by using various transition temperature criteria. This paper describes the investigation of a catastrophic failure of a large pressure vessel, the development of corrective heat-treatment for a large number of similar vessels, the control and testing involving bursting of a further sixteen vessels containing artificial defects and correlation with the more common transition temperature criteria. The basis of the corrective heat-treatment would not meet with unqualified approval in the U.K., but the results appear to have justified the means. The third of this group of papers is concerned with a number of high strength titanium alloys suitable for deep diving submersibles. The authors open with the now familiar observation that cracklike flaws will usually be present in service and therefore are concerned to establish whether a simple test method could be used to indicate a capacity for plastic deformation overloads in the presence of such flaws. For the order of plastic strains required, linear elastic analysis based on fracture mechanics was considered to be insufficiently developed and was not attempted. Using either the Charpy 'V' notch or with more sensitivity, the larger scale drop weight tear test, it is shown that the performance of this group of materials in full scale explosion tear tests can be predicted. No further explanation is offered although the Charpy 'V' notch is clearly more connected with fracture initiation than is either of the other tests. Surprisingly perhaps, no mention is made either for or against the use of pre-cracked Charpy specimens. One up for the transition temperature approach.

The remaining five papers describe separate major research programmes aimed at a basic understanding of the metallurgical factors including main composition, impurity levels, heat-treatment and mechanical history, which govern the fracture toughness of particular materials. These include welded maraging steels, high strength aluminium alloys, low carbon high strength alloy steels, ultra-high strength medium alloy steels and finally, extra work hardened chromium nickel stainless steel. Each of these papers is based on a formidable collection of experimental and test data related to material of direct engineering interest and would be of value for this feature alone. Extensive use is made of electron microscopy of polished specimens, fracture surfaces and in the final paper, thin films, including specimens undergoing tensile test within the electron microscope.

As a means of acquainting the metallurgist or engineer with the width of the field, the methods and difficulties of further exploring the problems in a quantitative way and the extent to which fracture mechanics can be made to work, even if still in a non-precise manner, the book is probably unique. Certainly no comparable collection of British work is known to-date and the U.K. reader may well be dismayed by the sheer weight of experimental data and scale of the investigations reported. However, there are several significant shortcomings. Most important, the analytical reader and particularly the research student will require a more precise and detailed treatment of the theoretical aspects of fracture mechanics and of the guide lines which determine the validity of the various test methods and test pieces. In its treatment of these matters, the book is slightly outmoded. Further, since many of the materials investigated are already in service the reviewer would have welcomed at least one paper fully devoted to quality control and acceptance tests, for example with clear proposals for standardized fracture toughness tests, at least for limited ranges of material.

One disadvantage almost inherent in this type of book is that whilst the individual papers were selected from a considerably greater number of submissions, the research programmes which they describe were not part of a single co-ordinated programme. Thus the overall

impression is one of width rather than depth of picture.

Otherwise, the book is well presented, with an admirable preface and each paper is clearly set-out with an abstract, introduction and conclusions. The references which are mostly American with a few British, number over 200 and surprisingly few are repeated. In spite of the rather open finish of the paper, the numerous photographs and photo-micrographs are of ample clarity. The proof reading has been sketchy and even the list of contents on the cover slip contains a typographical error. At 200s. the price is likely to deter many individuals and the book is more likely to be purchased by libraries and group users.

A. Muscott

The Theory of Order-Disorder in Alloys. By M. A. Krivoglaz and A. Smirnov. Pp. x + 427. London; Macdonald & Co. Ltd., 1964. Price 90s.

It is usually supposed that atoms are randomly arranged in those alloys which are solid solutions of one metal in another, with lattice sites occupied indiscriminately by the one or the other. Many cases are known where so to speak the non symmetry implied by the disorder is converted to a different form; a loss of the symmetry of the unit cell which is replaced by a larger one or by the loss of one of its symmetry elements. The phenomenon indeed proves more widespread than was thought earlier and occurs for example in brass. It is unlikely that a random arrangement would have the lowest energy and one reason why transitions between ordered and disordered states are not more often observed is the slow rate of solid state reactions.

The effect of order-disorder reactions on useful mechanical or other properties is generally small and the main interest is as a kind of reaction which is simple enough for a comprehensive theoretical approach to have some validity. In practical metallurgy it is a factor which may often be present and have some influence in modifying situations controlled by other factors.

The book generally reflects this attitude. The emphasis is on the theory including thermodynamics and statistical mechanics of the transitions, and the effects on scattering both of waves (x-rays) and particles (neutrons and electrons) which provide the main experimental approach. The effects on mechanical properties are briefly considered, and also on the magnetic and electrical properties where effects may be of greater practical significance.

It is useful to have these treatments gathered together even if it is a rather specialized topic. Reference is made to 150 Russian and 180 Western papers. The translation by an agency subsequently edited by Professor Chalmers is happily done, but there is no index.

D. E. Bromley

The Technology and Properties of Ferrous Alloys for High Temperature Use. By M. G. Gemmill. Pp. xii + 242. London; George Newnes Ltd., 1966. Price 70s.

This book is one of a series of Newnes' Monographs intended to provide information in various aspects of material science and technology. The author is a well known authority on the subject matter although his long association with the power generation industry tends to emphasize this particular application and the phrase "land power plant" appears with monotonous regularity. The 450 references included give the book the air of a review which does not always lead to easy reading.

Ferrous base alloys for high temperature service are discussed from both theoretical and practical standpoints. Modern deformation theory of metals is examined with respect to the effect upon time-dependent plasticity and high temperature fatigue. Testing procedures are examined and the limitations of conventional tests when applied to steels for high temperature usage are emphasized. Considerably more detail is included relating to the time-dependent tests, *i.e.* creep and fatigue which are of prime importance in high temperature service. The physical difficulties encountered in the design of modern creep testing machines are not discussed whilst the diagrammatic sketches of outdated machines, obviously taken from references, are left without the detailed description present in the original.

Steels used for high temperature purposes are examined in the categories of carbon, ferritic alloy, simple austenitic and complex austenitic types. The influence of steel-making practice upon the subsequent high temperature properties, particularly with respect to the effect of the interstitial and substitutional hardening of trace elements, is of value. World-wide alloy steel development over the years, as the high temperature properties required have been increased, is followed. Nineteen complex austenitic steels mainly developed for specific requirements are examined which show a preponderance of the use of the elements molybdenum, niobium, titanium and vanadium. Some discussion is also given to the role of trace element additions.

Corrosion resistance of the specific materials is discussed with respect to the particular environments encountered in the electrical power industry. The chapter on welding is a welcome innovation; few metallurgical text books deal with this important aspect of engineering in such detail. The physical metallurgy of welds is discussed using both ferritic and austenitic steels as examples. The engineering aspects of welding, including reported weld cracking problems in niobium bearing austenitic steels, are reviewed.

The final chapter on mechanical properties and high temperature engineering constitutes an attempt to cover the means in which mechanical properties of high temperature steels are translated into stress values of use to the engineer. Of necessity in a book of this size, the subject is only vaguely discussed and the chapter should be treated only as an introduction to this important subject.

The book is intended for final year students of metallurgy, materials science or engineering and to these people it will be of value. Graduate metallurgists, engineers, *etc.*, who wish to extend their knowledge to this aspect of engineering, will also benefit from having a copy in the bookcase.

R. Scholey

Low-Speed Wind Tunnel Testing. By A. Pope and J. J. Harper. Pp. ix + 457. New York and London; John Wiley & Sons Inc., 1966. Price 110s., and **High-Speed Wind Tunnel Testing.** By A. Pope and K. L. Goin. Pp. ix + 474. New York and London; John Wiley & Sons Inc., 1966. Price 165s.

These two interesting books are companion volumes and between them cover the techniques of wind tunnel testing over the complete range from low subsonic speed wind tunnels up to hypersonic tunnels and what are described as higher velocity facilities, *e.g.* shock tubes.

The volume on low speed wind tunnel testing is a major revision and bringing up to date of an earlier book by Pope entitled simply "Wind Tunnel Testing". Owing to recent developments of various forms of powered lift aircraft such as helicopters and V/STOL aircraft, and for that matter hovercraft, there is now a considerable interest in problems of low speed wind tunnel testing, a topic which during the past ten years

or so has suffered somewhat from being a poor relation of the rather more glamorous field of high speed wind tunnel testing.

"Low-Speed Wind Tunnel Testing" starts with a description of the various types of low speed tunnels including, for instance, spinning tunnels, free flight tunnels and V/STOL tunnels. This is followed by lists of the world's major low speed wind tunnels.

The chapter on wind tunnel design is written very much from the practical engineer's point of view to cover such items as choice of fan, screens and methods of cooling. This is followed by a section on instrumentation and calibration of the working section. Instrumentation covers various methods of measuring pressure, flow visualization techniques, turbulence measurements, and measurements of forces and moments by both mechanical and strain gauge type balances.

Testing procedure starts with model design and construction including for example flutter models. Tunnel scheduling is also covered, rather from the point of view of a commercial wind tunnel, and includes descriptions of somewhat unusual tests such as parabrakes, aircraft stores and re-entry landing craft, as well as regular aircraft model testing. There is a useful chapter on wind tunnel corrections followed by an important one on the interpretation of wind tunnel data.

Non-aeronautical use of wind tunnels covering such problems as air flow over building structures, chimney stacks, ships' funnels and of some interest to us, tests of underwater vehicles, ships and sails, is also dealt with briefly.

The last chapter of the book is concerned with the important topic of testing helicopters and goes into some detail on the design and manufacture of rotor models and special rotor instrumentation.

The companion volume on high-speed wind tunnel testing starts with a description of the tunnel types and uses and follows with a brief summary on high speed wind tunnel theory including supersonic nozzle design by the method of characteristics and also graphs and tables in the effects of gas imperfection on various wind tunnel parameters.

There then follows a long section on the design of blow down, vacuum and pressure vacuum wind tunnels in which various engineering aspects of their design including effects of running time, starting pressure ratio, storage pressure and details of the duct work are discussed in some detail. Flow control devices and methods of cooling and heating the air are also covered for all the various types of tunnel.

The chapter on the continuous-closed circuit tunnels covers the choice of the type of compressor as well as cooler and heater designs. Also, it covers such matters as suitable choice of materials for use in nozzles which is based on strength at elevated temperatures.

The section on instrumentation is concerned with air measuring devices including pressure and temperature measurements and also the use of flow visualization techniques covering shadowgraph, schlieren and interferometers. Boundary layer visualization both by china clay and oil flow techniques are also briefly covered. Force and moment measurements is mainly covered by a description of the design of various forms of resistance strain gauge balances; some mention is also made of dynamic derivative rigs.

As in the volume on low-speed wind tunnel testing the instrumentation section is followed by a chapter covering model design and construction, testing procedure and data reduction. It is felt that this most important section could, with advantage, have been somewhat expanded.

The penultimate section is concerned with calibration methods and the use of transonic, supersonic and hypersonic wind tunnels respectively. Each chapter ends with the useful list of the appropriate high-speed wind tunnels that exist in the world.

The last chapter deals with what is termed "hypervelocity facilities" which include hotshot tunnels, shock tubes, plasma arc tunnels, and light gas guns. Once again it is completed by a list of hypervelocity facilities that are known to exist.

Problems arising from low density and high stagnation temperature and the considerable experimental difficulties of making measurements such as heat transfers during the extremely short running times available are considered in this last chapter.

Both books are definitely written from a strictly practical viewpoint and are obviously intended for use by people directly concerned with wind tunnel operation. From this point of view they are excellent and cover the ground very thoroughly. Readers looking for a more thorough theoretical and mathematical treatment of the problems might be somewhat disappointed.

F. S. Burt

Coal and the Power Industries in Postwar Britain. By E. S. Simpson. Pp. 170 with 17 figures. Paperback. London; Longmans, Green & Co. Ltd., 1966. Price 17s. 6d.

How many megawatts of power can the United Kingdom generate for its industrial and domestic use? Surely this is a most vital statistic in this highly populated and industrialized country, yet it is doubtful if one layman in a thousand could quote a figure that would even be of the right order of accuracy. How much of this power is now produced by coal, and how much is likely to be produced in the future by oil, natural gas and nuclear sources? What are the costs of production? Why, when for the last 30 years coal production has been of the order of 200 million tons annually, plus or minus 30 millions, is the Coal Board now to make every effort to cut down output to 155 million tons by 1970, with substantial closures including perhaps even highly mechanized pits, and a redundancy of possibly 135,000 men?

The reader of Mr. Simpson's small but excellent book may expect to find not so much up-to-date answers to the above questions, but rather a revealing historical background of recent years against which the answers can be understood and appreciated. The book deals dispassionately with the production and use of coal, with gas and electricity generation and distribution, and with oil refining and the beginnings of nuclear power in the service of man. There are many tables of relevant statistics, and a number of maps of which the last shows the oil-exploration concessions in the North Sea.

The reader will learn how in 1950 the newly created National Coal Board decided to raise coal output, and how in 1952 the Ridley Committee on National Policy for the use of Fuel and Power Resources considered even the NCB's forecasts of demand for coal to be too low. The need for coal was then in fact so great that the unprecedented and expensive action was taken of importing coal from America. Then in 1957 the pendulum began to swing the other way. Production was up, but the hitherto existing shortage of coal of the right sort had produced the obvious reaction of stimulating greater efficiency in its use and of allowing alternative fuels to come into their own. Coal began to stockpile, and in 1961 consumption had fallen to 190 million tons compared with the Ridley Committee's forecast of 232·5 millions. Oil fuel had taken up 20% of the national demand for power.

But the Suez crisis had shaken the tendency to rely on steadily increasing supplies of oil. A new star had been rising. In 1955 there had appeared the Government document "A Programme of Nuclear Power" in respect of which Mr. Simpson dryly comments that it came "A mere two and a half years after the Ridley Committee's report, in which nuclear power received less attention than peat . . . ". With the object not of replacing but rather of supplementing coal, the Government planned 12 nuclear power stations by 1965 at a cost of £300 million to generate between 1500 to 2000 megawatts, the equivalent of 5 to 6 million tons of coal annually.

Now in 1967, with dramatic decreases likely in the production costs of nuclear-generated electricity, and with North Sea gas on the threshold, the whole pattern of energy supply both for domestic and industrial purposes may well undergo a remarkable transformation. In ten or twenty years time a piece of coal, once the commonest of household objects, may become as rare a sight in London as a salmon in the Thames. Mr. Simpson's guide to this change and decline in the use of coal for economic reasons, and the growing significance of its competitors, can be recommended to anyone who wishes both to be given a lucid and convincing account of the recent historical build-up towards the present revolutionary situation, and to be able to comprehend future developments.

L. S. LePage

Effects of Polluting Discharges on the Thames Estuary (Water Pollution Research Technical Paper No. 11). Pp. xxviii + 609. H.M.S.O., 1964. Price 252s.

This volume, of some 600 pages and weighing 5 lbs. is the report of the Thames Estuary Survey Committee which was appointed in 1948 to study the condition of the Thames Estuary and its capacity to purify the polluting effluents discharged into it. A mass of detailed information was collected in the ensuing years culminating in the publication of the report in 1964.

Two chapters of the report deal with the sources and early history of pollution in the Thames showing that the condition of the river gave rise to anxiety as early as 1620. The effect of oxygen content, considered to be the most satisfactory single indicator of the river condition, is dealt with at great length establishing a clear picture of the menace of the pollution problem over the last 80 years. It is encouraging to note that while the condition of the river gradually deteriorated in the years prior to 1959, the installation of new aeration plant significantly reduced in length the reach of river devoid of dissolved oxygen. The detailed manner in which the report considers the effect of oxygen and the reduction processes producing sulphide makes it of especial value to those in the Service concerned with the problem of corrosion in estuarine waters.

In addition to the tabulation of collected data the report deals thoroughly with the methods of sampling used and the statistical analysis of factors involving the river condition, and compares observed and calculated pollution distributions. The penultimate chapter deals with predictions of future conditions in the river.

B. Angell

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Offers to review should be addressed to the Editor

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C. J. Dakin and C. E. G. Cooke.
Iliffe Books Limited. 1967. 105s. (No. 1561).

Electronic Counting Circuits.
J. B. Dance.
Iliffe Books Limited. 1967. 85s. (No. 1562).

Theory of Automatic Control.
H. Takai.
Iliffe Books Limited. 1967. 75s. (No. 1563).

Hydraulic and Electrohydraulic Servo Systems.
R. Walters.
Iliffe Books Limited. 1967. 45s. (No. 1564).

Progress in Applied Materials Research. Volume 7.
Edited by E. J. Stanford.
Heywood Books. 1967. 95s. (No. 1565).

Fundamentals of Electronics. Second Edition.
J. Blitz.
Butterworth and Company (Publishers) Limited. 1967. 38s. (No. 1566).

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C. W. Kilminster.
English Universities Press Limited. 1967. 25s. (No. 1569).

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McGraw Hill Publishing Company. 1967. 81s. (No. 1570).

ABC's of Varactors.
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W. Foulsham and Company Limited. 1967. 30s. (No. 1575).

Rocket and Space Science Series. Volume 1. Propulsion.
Edited by B. Ketcham and R. C. Martin.
W. Foulsham and Company Limited. 1967. 30s. (No. 1576).

A New Guide to Modern Valence Theory.
G. I. Brown.
Longmans Green Company Limited. 1967. 21s. (No. 1580).

Ebert Physics Pocket Book.
Edited by H. Ebert.
Oliver and Boyd. 1967. 63s. (No. 1581).

Graphs and Dynamic Programming and Finite Gains.
Edited by A. Kaufmann.
Academic Press. 1967. 116s. (No. 1582).

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